984

1.0

2.8   2.5

3.2   2.2

3.6

4.5   2.0

1.1

1.8

1.25   1.4   1.6

MICROCOPY RESOLUTION TEST CHART

AD A109840

EVALUATION OF DCS III TRANSMISSION ALTERNATIVES PHASE II TASK 1 FINAL REPORT

31 AUGUST 1981

Prepared for
Defense Communications Agency
Defense Communications Engineering Center
Reston, Virginia 22090

Contract No. DCA 100–79–C–0044

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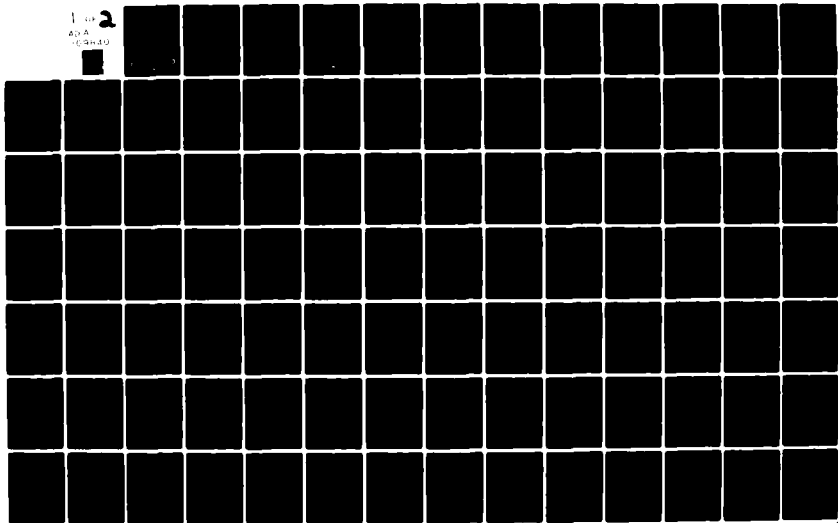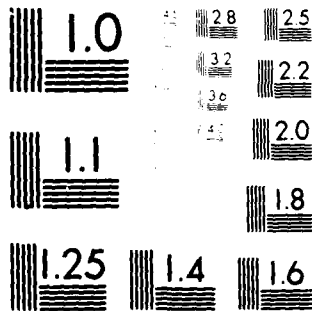
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This report is one of a series that document the study, analysis, and evaluation of the use of advanced communications technology in the Defense Communications System. The purpose of the overall study was to project the capability of potential transmission media into the future, and to assess their comparative utility for DCS application in the years 2000 and beyond. This phase and task of the study focused on the results of Phase I, which indicated the greatest potential was in application of millimeter wave LOS radio and in fiber optic transmission. This report contains the design of DCS network alternatives

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using these media in Central Germany and in Hawaii.

EVALUATION OF DCS III
TRANSMISSION ALTERNATIVES
PHASE II TASK 1 FINAL REPORT

31 AUGUST 1981

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FOREWORD AND ACKNOWLEDGEMENT

This Phase II Task 1 Final Report is the first of the reports of the Phase II effort of Evaluation of DCS III Transmission Alternatives Study. Reports of the Phase I effort consist of four volumes. These volumes are:

1. Phase IA Final Report, Evaluation of DCS III Transmission Alternatives, AD 101359

2. Appendix A, Transmission Media, AD 101360

3. Appendix B, Regulatory Barriers, AD 101361

4. Appendix C, Regional Consideration and Characterization, AD 101362.

Project work, as documented in the above noted reports and appendices, has been performed by the Defense and Space Systems Group, TRW Inc., and by TRW's subcontractor, Page Communications Engineers, Inc., Northrop Corporation, for the Defense Communications Engineering Center, Defense Communications Agency, under Contract No. DCA 100-79-C-0044.

This project has been managed by Dr. T. M. Chu and is supported by Messrs. S. H. Lin, and D. Segel, Dr. C. Y. Yoon, and by other TRW personnel on an as-required basis. Subcontracted work has been managed by Mr. R. A. Pickens and is supported by Messrs. T. Loeffler, P. Hill, and other personnel.

Gratefully acknowledged are the many helpful discussions, suggestions, and guidance offered by Mr. J. R. Mensch of the Defense Communications Engineering Center, throughout the course of this study.

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1.0 INTRODUCTION

This report documents the results of the Task 1 of the Phase II effort of the "Evaluation of DCS III Transmission Alternatives" study. This study was conducted for the Defense Communications Engineering Center (DCEC), Defense Communications Agency (DCA) in accordance with Contract No. DCA100-79-C-0044. It was performed by the Defense and Space System Group, TRW, Inc. and by TRW's subcontractor, Page Communications Engineers, Inc., Northrop Corporation.

Since the results presented in this report are only a part of the second year effort of a two year contract, it is deemed helpful to recognize, in advance, the objectives and scope of the DCS III Study program. With this background information, the results presented here can then be placed in the proper perspective for those readers who have not read the Phase I reports (Ref. 1-1 and 1-2). Therefore, the purpose, scope and objective of the entire DCS III Study program and particularly those of Phase I are discussed in this section. A summary of Phase I results and findings are given in the following Section 2.

1.1 PURPOSE OF THE DCS III STUDY PROGRAM

The Defense Communications System (DCS), since its establishment in 1960 has been in a continuous process of growth and evolution. This process is a direct response to the changes of requirements and the advancement of communications technology. The DCS is currently in the transition period from an analog system to a first generation digital system. According to various project plans and schedules, components of the digital DCS will be implemented during the period of FY 80 to FY 85 and will be fully operational by FY 85. This consists of AUTOVON, AUTOSEVOCOM, The integrated AUTODIN System (IAS), the upgraded and digitized terrestrial transmission systems and DSCS II/III.

As a general rule, the life span of communications systems and electronics is about fifteen years. Therefore, by the year 2000, the DCS now being implemented needs to be gradually replaced by either new and exactly the same equipment or by systems and equipments utilizing new transmission media and/or communications technologies which are either

currently being developed or would be developed from now to the year 2000. This will result in a future DCS, termed DCS III in this report.

It usually takes five to ten years to develop a new system, from the time of formulating a system concept to the time of implementing the developed system. A longer period of time is required when new and unproven technology is utilized. Therefore now is the time to examine alternatives for implementing the future DCS transmission subsystem.

To provide a basis for the evolving architecture design of the third generation DCS for the years beyond 2000, it is necessary to identify alternative transmission media, communication technologies, system engineering concepts and designs. In addition, international, regional, and national regulatory barriers which may impact alternative media and transmission system designs need to be identified and documented. To be able to judge the practical utility of each transmission medium, networks using the various media are designed to fulfill specified requirements. Then, each of the various networks' performance and cost are evaluated and estimated for comparison.

In summary, the primary purpose of the DCS III Study Program is to project the capability of potential transmission media and to assess their comparative utility for DCS in the years beyond 2000.

1.2 SCOPE OF THE DCS III STUDY PROGRAM

The DCS III study is composed of two phases and seven tasks as listed below:

1. Phase I:

    a. Phase IA:

        Task 1. DCS III Transmission Media Alternatives

        Task 2. Development of Evolving DCS Transmission System Alternatives

        Task 3. Identification of Technology and Regulatory Barriers.

    b. Phase IB:

        Task 1. Comparative Evaluation of Alternatives

        Task 2. Relative Cost.

2. Phase II:

   Task 1. Overlay of Special User Transmission Requirements

   Task 2. Reevaluation of Alternatives.

Phase IA and Phase IB constituted the first year effort of the DCS III study program and Phase II constitutes the second year effort. Phase IA and Phase IB have been completed and the results presented in a five-volume Phase I report (Ref. 1-1 and 1-2):

1. Phase IA Final Report, Evaluation of DCS III Transmission Alternatives, AD 101359

2. Appendix A, Transmission Media, AD 101360

3. Appendix B, Regulatory Barriers, AD 101361

4. Appendix C, Regional Consideration and Characterizations, AD 101362

5. Phase IB Final Report, Evaluation of DCS III Transmission Alternatives, AD 101363.

   The scope of the Phase II effort has been refocused and expanded somewhat in accordance with the guidance issued at the beginning of this phase. These changes were made because of the results and findings of the Phase I work. The modified scope of the Phase II effort is described and discussed in Section 3.1.

1.3 OBJECTIVE OF DCS III STUDY PROGRAM

   The objective of Task 1 of Phase IA was to identify promising transmission media for the DCS III time frame, to assess or forecast capability, to examine limitations and restraints, and to recommend needed research and development effort to resolve uncertainties in applications. The objective of Task 2 of Phase IA was to develop two candidate transmission systems employing appropriate transmission media for certain specified areas, satisfying the required capacities and connectivities of each area. Three areas of interest are specified for this purpose. These areas are Oahu Island of the Hawaiian Islands, the central portion of the Federal Republic of Germany, and Turkey. The objective of Task 3 of Phase IA is self-explanatory. Related international, regional and national regulations, rules, procedures, standards, and recommendations which have impact on transmission system

design are collected, organized, and reviewed.

The objectives of Phase IB were to comparatively evaluate the performance and cost of those alternative transmission systems developed in Task 2 of Phase I. In Task 1, of Phase IB, system performance measures were defined and evaluation methodology developed for each medium. Then system performance of each candidate alternative design was evaluated and compared. In Task 2, the life cycle cost of each of the candidate transmission systems was estimated. Those costs include the cost of development, acquisition, operation, maintenance, and support of the system.

The objective of the Phase II effort, in accordance with the Statement of Work is twofold. The first task is to overlay wideband user's requirements on the common user alternative transmission systems designed in Task 2 of Phase IA for the three specified areas. The second task is to evaluate performance of those alternative systems supporting both common user and wideband user needs, and to estimate life-cycle cost of those systems for both common and wideband users. However, the Phase II objective, due to the findings of Phase I effort, has been modified as stated at the end of Section 1.2. The modified objective of Phase II is given in Section 3.1.

1.4 ORGANIZATION OF PHASE II TASK I REPORT

This report is organized into eight sections of which this is Section 1, Introduction. Figure 1-1 depicts all sections and their relationship.

Section 2, entitled Summary of Phase I Effort, describes the findings and results of the Phase I effort and emphasizes these materials which impact Phase II. Section 3 provides a brief summary of the guidance for Phase II issued by the government and discusses the assumptions used for alternative system design. In Section 4, three RF transmission system models are presented and discussed. These models are to be used as building blocks for alternative network designs. Section 5 presents network design methodology developed for the present task, and this methodology is then followed to design the alternative network designs for Oahu, Hawaii and Central Germany in Sections 6 and 7 respectively. Summary and preliminary conclusions are presented in Section 8.

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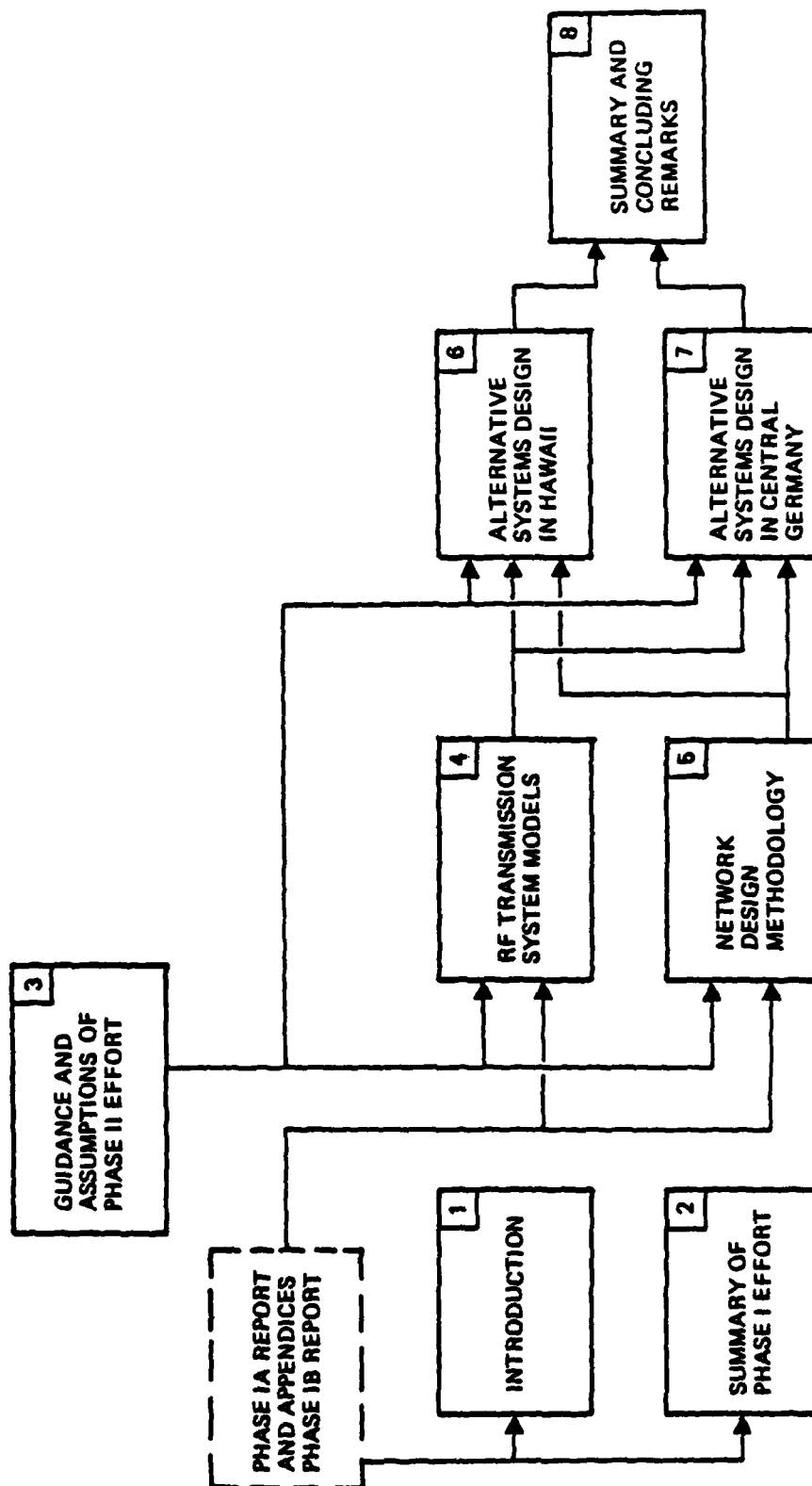
Figure 1-1 Organization of Phase II Task 1 Report

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2.0 SUMMARY OF DCS III PHASE I STUDY RESULTS

The results of the Phase IA and Phase IB effort are briefly summarized in Sections 2.1 and 2.2 respectively. The impacts of these results upon the Phase II work are presented in Section 2.3.

2.1 SUMMARY OF PHASE IA REPORT

Task 1 identified four broad categories of promising transmission media deemed worthy of study. These categories are guided wave utilizing a conductor, radio wave utilizing radiated energy, airborne relay platforms and other alternatives to electromagnetic communication waves. The media considered in each group are listed in Table 2-1. All medium were subjected to extensive study. The performance parameters of each media are summarized in the Phase IA Final Report and further developed in Appendix A of that report (Ref. 1-1).

It was concluded that in light of the three geographical areas of implementation, attention was focused on coaxial cable, optical fibers, millimeter waves, EHF satellite, aircraft and tethered ballons as the most promising media worthy of further detailed study.

These six media were applied in Task 2 to the development of two candidate transmission systems for each area of interest as shown in Table 2-2. Initial action consisted of gathering information on the existing and planned DCS trunks in each of the three areas. This information was for the most part derived from DCA drawings and trunking documents. Major topics addressed were:

- Network trunking requirements analysis

- Topographic and climatic considerations

- Regional characteristics considerations

- Frequency band availability

- Medium or media selections

- Network design.

The reports do not reflect consideration of multiplexer, and switching schemes because of instruction from DCA. It is assumed that

the DRAMA multiplexer equipment will be used for DCS III.

Table 2-1. Alternative Transmission Media Investigated

I.	Guided Waves
	1. Coaxial Cable
	2. Millimeter Waveguide
	3. Beam Waveguide
	4. Optical Fibers
	5. Submarine Cables
II.	Radio Waves
	1. Terrestrial Microwave Line-of-Sight Transmission
	2. Tropospheric Scatter Communication
	3. Millimeter Waves
	4. EHF Satellite
	5. Packet Radio
	6. Meteor-Burst Communications System
	7. Radio Frequency Spectrum
III.	Airborne Relay Platform*
	1. Manned and Unmanned Aircraft
	2. Tethered Balloon
	3. High Altitude Powered Platform
IV.	Alternatives to Electromagnetic Communication Links
	1. Gravitational Waves
	2. Subnuclear Partical Beams

* Strictly speaking, airborne relay platforms are not transmission
  media but can be used to extend line-of-sight ranges.
  Investigation of such platforms has been specified in the
  Statement of Work for the DCS III study.

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Table 2-2. Proposed Alternative Transmission Systems

SPECIFIED AREA	PROPOSED ALTERNATIVE SYSTEMS
Oahu Island, Hawaii	1. Millimeter Wave Relay System 2. Buried Cable System (Coaxial Cable or Optical Fiber)
Federal Republic of Germany	1. Airborne Communications System (Tethered Balloon or Aircraft) 2. Buried Cable System (Coaxial Cable or Fiber Optics)
Turkey	1. EHF Satellite 2. Airborne Relay System

System designs were prepared for each of the two alternatives in each area of interest, showing, nodes, links, path distances and number of channels and spares per link. Consideration was given to various network topologies (i.e. star, mesh.). Finally each media employed in an alternative was tailored to the environment and network requirements.

Task III generated a detailed review of rules, procedures, regulations, standards and recommendations established by international, regional and national organizations and agencies. These organizations include the International Telecommunications Union (ITU), International Radio Consultative Committee (CCIR), International Telegraph and Telephone Consultative Committee (CCITT) and U.S., German and Turkish civil and military national regulations.

This task also produced a detailed study of topographic and climatological study of the three regions under consideration. This study provides information relative to the placement of LOS terminals and repeaters as well as study of those attenuation factors such as rain and

snow that adversely affect millimeter wave transmission.

2.2 SUMMARY OF PHASE IB REPORT

Task 1 identified three measures adopted by TRW to evaluate the
system performance of a transmission media. Primarily, quality of
channels is measured by bit error rate (BER). Secondly, time availability (TA)
is measured by the percentage of time the quality of a channel is at
least equal to or better than a specified BER. Finally, synchronization
characteristics of the system are measured by Mean Time Between Loss of
Bit Count Integrity (MLBCI).

Utilizing these three measures, a system performance evaluation
methodology was devised for each of the media. These developed
methodologies were then applied to the proposed transmission alternatives
for performance comparison.

Quantitative data rates and link lengths were established, fade
margin calculation parameters were determined for LOS systems, dispersion
effect and power requirement quantification methods were determined for
fiber optic systems and power budget calculation techniques established
for satellite and relay systems.

The methodology developed may be applied to any communications systems,
however, for purposes of this study, the methodology was applied to the
two alternative networks proposed for each of the three areas of concern
resulting in a comparative performance evaluation of the networks. Each
network was evaluated in terms of BER, time available and synchronization
characteristics.

Phase IB concluded with life-cycle cost projection of each
alternative system under consideration. The following assumptions and
ground rules were adopted prior to the costing exercise that apply in
general to all networks regardless of media employed:

1. Cost estimates were made for transmission media only.
    Multiplexing and demultiplexing equipments, switching equipments
    were excluded in the cost estimates.

2. The multiplexing format of currently available and developing
    equipment such as AN/FCC-98 and AN/FCC-99 is assumed.

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3. Acquisition costs include materials, initial spares, supporting test equipment, system engineering, purchasing, and program management costs necessary to acquire and ship the system components, and detail the installation criteria and instructions. Specifically not included were civil works (buildings, shelters, etc.), power generating equipment and Heating, Ventilating, and Air Conditioning (HVAC). It was assumed that all equipments and documentation are produced to best commercial standards.

4. Deployment costs include all labor and associated facilitating costs necessary for the installation, test, and cutover of the systems. These costs do not include acquisition of land, rights-of-ways, etc.

5. Initial development cost was applicable only if development is required and is unique to the candidate system.

6. "Spares consumption" includes calibration and maintenance costs of test and support equipment as well as replenishment of the initial spares complement.

7. "Operation and maintenance" costs include estimates of labor, and facilitating support, necessary to maintain normal communications requirements. Special procedures as might be necessary for extreme availability requirements were not accounted for. It was further assumed that operation and maintenance would be integrated into the existing support structure of the DCS.

8. Sustaining costs include "spares consumption" and "operation and maintenance." Other possible supporting costs, such as power and HVAC.

9. Life-cycle cost is simply total initial cost plus total sustaining cost for 10 years.

The system life-cycle cost of the six proposed transmission systems in the three areas of concern with dollar cost rounded to the nearest million is shown in Table 2-3.

Table 2-3. Transmission Alternative Systems
Cost Summary (1980 Dollars, $ Million)

| | HAWAII | | | CENTRAL GERMANY | | | | TURKEY | |
| | Millimeter Wave LOS | Buried System | | Airborne Relay | | Buried System | | EHF Satellite | Airborne Relay (Aircraft) |
		Optical Fiber	Coaxial Cable	Aircraft	Tethered Balloon	Optical Fiber	Coaxial Cable		
1980 Technology	41	17	72	88	85	52	131	75	119
2000 Technology	13	10	72	65	67	34	131	49	85

2.3 IMPACT OF PHASE I EFFORT

The results of the Phase I effort were utilized by DCEC to provide guidance for this Phase II effort as stated in Section 1.2.

Major changes in the scope of the Phase II of DCS III study include the elimination of the sparsely populated Turkish area from consideration and the consideration only of microwave, millimeter wave and optical fiber transmission media for utilization in the German and Hawaiian areas.

The proposed manned aircraft as an alternative for the Turkish area proved to be too costly to implement due to the need for two relay points, aircraft endurance, flying crew fatigue and logistics support. The other Turkish alternative proposed an EHF satellite system which while performing satisfactorily at about one-half the life cycle cost of the manned aircraft, however EHF satellite has been studied intensively elsewhere and thus also was eliminated from further Phase II consideration. Thus the Phase II effort was directed to eliminate consideration of Turkey and concentrate only on the German and Hawaiian areas.

Coaxial cable transmission evaluated for use in Hawaii and Germany was discarded as a suitable media for the Phase II effort in favor of optical fiber cable transmission. This decision was based on the wide disparity in cost between the two buried cable media. Although both media exhibit performance characteristics adequate for DCS III needs, in terms of 1980 technology, fiber optic implementation costs were found to be only 24% of coaxial cable cost, and in terms of projected year 2000 technological advances in fiber optic implementation was projected as only 14%.

The tethered balloon relay evaluated as one of the alternatives for German implementation was eliminated from further consideration as it was found to be bulky and subject to sabotage.

The Phase I study clearly indicates that only microwave, millimeter wave and optical fiber media should be considered as implementing media for the Phase II study. Use of these media either singly or in combination, utilizing either a Government-owned or a commercial lease environment provides the basis of the Phase II study.

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3.0 GUIDANCE AND ASSUMPTION OF PHASE II EFFORT

This section presents the guidance of Phase II effort provided by the government and adopted assumption for the study. Measures of system and network performance are also defined and discussed in this section.

3.1 GUIDANCE OF PHASE II EFFORT

As was stated in Section 1.2 and 1.3, the two tasks to be accomplished for Phase II have been modified in accordance with new guidance upon completion of the Phase I effort. These modifications are briefly discussed in the following subsections.

3.1.1 Specific Areas and Media

Only two areas, Hawaii and Germany will be considered in Phase II. Turkey, which was discussed in Phase I, will not be addressed. For Hawaii, the following media should be considered:

- Microwave line-of-sight links

- Millimeter wave radio line-of-sight links

- Fiber optic cables

- Wideband commercial leases.

In Central Germany, the following media should be considered:

- Microwave line-of-sight links

- Millimeter wave radio line-of-sight links

- Microwave and millimeter wave Mixture I

- Microwave and millimeter wave Mixture II

- Cost sharing fiber optic cables.

Each alternative shall satisfy the performance objectives stated in Section 3.1.2. Emphasis shall be placed on making the fullest use of millimeter wave radio transmission. Because of the distances between transmission nodes and the availability requirements, it will be necessary to select additional repeater sites for certain millimeter wave radio links. These site locations shall be based on the following order of preference:

3-1

- U. S. Government Facilities

- Germany Military Facilities

- German Government Facilities

- Other.

Site surveys shall not be performed. Site selection shall be accomplished through the use of topographic maps.

3.1.2 Performance Objectives

The performance of each alternative network shall be reevaluated in Task 2, and shall follow the allocation of availability contained in draft MIL-STD-188-XXX (Ref. 3-1). The reevaluation shall be based on performance under both normal and stressed conditions. For the purpose of this analysis, the stressed conditions will be represented by the deletion of links from the network (representing physical or electromagnetic disruption).

Definitions of End-to-End (ETE) Availability and Mean Time to Loss of Bit Count Integrity (MTLBCI) are given in DCEC TR 12-76, DCS Digital Transmission System Performance (Ref. 3-2). The evaluations shall be made at the following points:

- ETE Availability of 0.95 and MTLBCI of 24 hours

- ETE Availability of 0.90 and MTLBCI of 12 hours

- ETE Availability of 0.99 and MTLBCI of 24 hours at link capacity reduction of 0, 10, 20, 30, 50 percent

- ETE Availability of 0.99 and MTLBCI of 24 hours at throughput reductions of 0, 10, 20, 30 and 50 percent with the random disruption of 10, 20, and 50 percent of all links.

3.1.3 Cost Analysis

Cost analysis shall be performed in Task 2 for each of the above performance conditions. This cost analysis shall consist of the non-recurring cost to implement the configuration, the yearly operating cost, and the lifetime cost - ownership.

3.1.4 Link Connectivity Requirements

It is not necessary to separate wideband user links from common user

links in the network design because the same set of repeater sites and radios can be used to support both kinds of traffic.

The wideband user shall be provided 15 Mbps with a long-term average bit error rate no greater than 10^{-7}. At least two alternative paths shall be provided for each wideband user link to meet a required availability which should not be less than 0.99.

The widebans user links to ob overlayed in Hawaii and in Central Germany are shown in Table 3-1.

TABLE 3-1. WIDEBAND USER LINKS

HAWAII			GERMANY		
Wahiawa	-	Hickam	Landstuhl	-	Boerfink
Wahiawa	-	Hickam	Landstuhl	-	Ramstein
Wahiawa	-	Pearl Harbor	Landstuhl	-	Frankfurt
Wahiawa	-	Wheeler	Landstuhl	-	Heidelberg

3.2 GROUND RULES AND ASSUMPTIONS FOR TRANSMISSION ALTERNATIVE DESIGN

The overall effort presented in this report and specifically the DCS III Transmission Alternative designs developed in Sections 6 and 7 are heavily influenced by some ground rules and ass-mptions. Among these rules and assumptions are some govenment directions imposed upon this study program because of limited requirements data, and some that bound the scope of the study due to limited resources and performance time. Major rules and assumptions are explicitly stated here to avoid possible confusion.

1. Required communications capacity is given in terms of either number of voice channels or number of digroups. This capacity includes 20% spare or growth capability.

2. The current Digital Radio and Multiplex Acquisition (DRAMA) program equipment is assumed to have been deployed for the baseline DCS.

3. The FCC-98 multiplexer/demultiplexer and FCC-99 multiplexer/demultiplexer formats are assumed to continue in use during the DCS III time frame.

4. Therefore, the lowest digital input data rate considered in this study program is the T1 channel rate, i.e., 1.544 Mbps. Each digitized voice channel is 64 kbps.

5. The alternative transmission design is limited to RF carrier capability only. Switching is not considered in the network design. This is because only link traffic information is available--number of voice channels, number of T1 channels, and wideband requirement (15 Mbps) between two nodes. Traffic statistics, such as calling rate, call duration and distributions, will not be considered.

6. The evaluated system performance in a stressed condition is to be expressed in terms of average network availability as discussed in Section 3.4. Each node is assumed to have the necessary switching equipment for traffic rerouting.

7. One important factor of alternative design is to attain a certain degree of survivability, therefore, the designed networks are provided with some redundant links to form loops for traffic re-routing. However, these designs are not optimized. System performance evaluation and network upgrading will be addressed in Task 2.

8. The network designs in the specified areas are treated as separated and independent entities; no interconnections with other parts of DCS is considered.

3.3 SYSTEM PERFORMANCE MEASURES

The performance of a transmission system can be expressed by two major parameters: the quality of channels and the availability of channels. The basic quality measure for a digital transmission system is its error performance. This is particularly true for a system using one or more repeaters which regenerate digital signals, because errors are accumulated through tandem sections of the system. Error performance can be specified by bit error rate (BER) and bit count integrity (BCI).

3.3.1 Bit Error Rate

There are two different modes of errors in a digital transmission system: One is the long-term steady state error rate, the other is the short-term dynamic state error rate.

An average BER of 10^{-6} is specified as the acceptable threshold for long-term steady state error rate conditions (Ref. 3-1). In other words,

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the system is unavailable when its steady state BER is greater than 10^{-6}. But for a wideband user link, 10^{-7} BER is considered as the threshold, that is, one order of magnitude more stringent than that of the common user link.

For a dynamic state error performance, the average BER alone is not appropriate because the BER cannot describe a short burst of errors which results from multipath propagation. Thus, fade outage is introduced to measure temporal distribution of error bursts. Fade outage is defined as the event that begins when the highest signal level on any diversity branch of a link falls below the specified threshold corresponding to a 10^{-4} bit error probability, and ends when the highest signal level on any diversity branch has again risen through the threshold value (Ref. 3-2). Five ranges of fade outages are defined, one of which is considered to be negligible from the user's point of view, one of which is of sufficient duration to be included in the unavailability specification, and three which are proposed to be controlled by separate probability of occurrence. (Ref. 3-1). A detailed list of five ranges of fade outages appear in the Phase IB report and other documents such as DCEC TR 12-76 and DCEC EP 27-77. (Ref. 3-2 and 3-3).

3.3.2 Availability Allocations

Availability is defined by the ratio of cumulative time that the system is not in an outage condition; to the cumulative time that the system is in operation, where an outage is defined as any one of the following: (Ref. 3-2)

a) Loss of path continuity for a period in excess of one minute

b) Error rate on either mission bit stream in excess of 10^{-6} for a period in excess of one minute

c) Fade outage rate in excess of five per minute for period in excess of one minute

The end-to-end (ETE) availability of 0.99 was specified in Section 3.1.2 as a required minimum. The value is for the global reference circuit 19,308 km (12,000 mi) long, which consists of four segments: A leased common carrier segment of 3,862 km (2,400 mi) length spanning the Continental United States; two satellite segments of one hop each; and an overseas terrestrial segment of government-owned LOS and troposcatter facilities 3,862 km in length.

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The availability for each segment or link can be derived from the value 0.99 assigned for the global circuit and the assumption that outages of each setment or link occurs independently with others.

In order to obtain the availability for each link, the value for each segment is obtained first. From the assumption that the unavailability due to equipment failure is greater than that due to propagation effects, a relative unavailability allocation ratio of four to one between the terrestrial segment and the satellite segment has been made because the satellite segment has less equipment than the terrestrial segment. The representative global DCS reference circuit and 965 km (600 mi) DCS voice reference channel are shown in Figure 3-1. The given unavailability 0.01 has been allocated as follows: (Ref. 3-1)

CONUS common carrier segment	4×10^{-3}
Satellite segment #1	1×10^{-3}
Satellite segment #2	1×10^{-3}
Overseas terrestrial segment	$\underline{4 \times 10^{-3}}$
	1×10^{-2}

Leased common carrier and DCS terrestrial transmission facilities have approximately equal unavailability allocations. However, that may not be a good assumption for overseas leases. The unavailability allocations for the CONUS common carrier segment and the overseas terrestrial segment are 0.04. Since they are composed of four identical 965 km (600 mile) channels in tandem, each voice reference channel has a 0.001 unavailability allocation. This allocation must be divided by the four-to-one ratio between equipment outage and propagation outage.

3.3.2.1 Microwave LOS Link Availability

As explained earlier, 0.001 (1×10^{-3}) unavailability is assigned to the 965 km voice reference channel. Since troposcatter link experience long-term outages more often than LOS link, the same unavailability is allocated to one troposcatter link or to fourteen LOS links. In order to obtain an unavailability allocation for a single 48 km link, the following steps are illustrated:
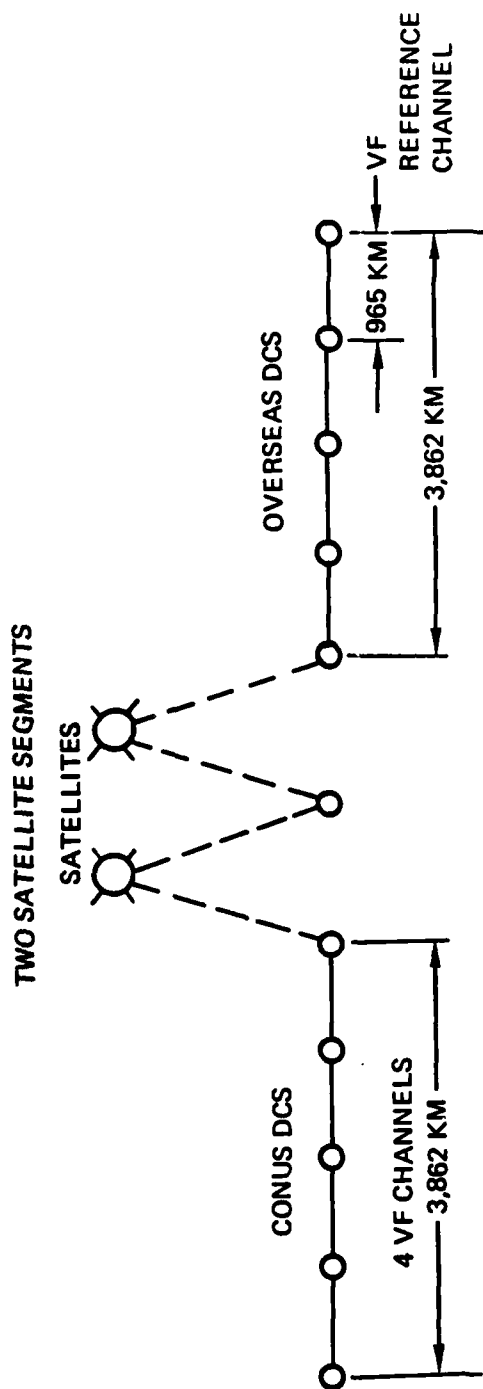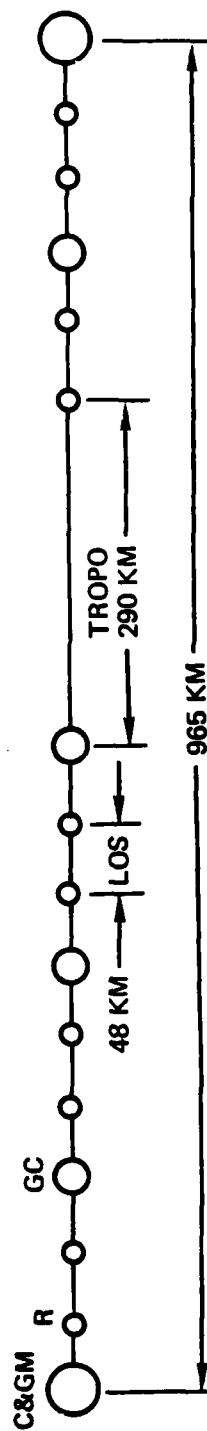
Figure 3-1 DCS Reference Configuration

1. Unavailability allocation to the 19,308 km Global reference circuit; 10^{-2}

2. Unavailability allocation to the 3,862 km terrestrial segment; 4×10^{-3}

3. Unavailability allocation to a 965 km voice reference channel; $4 \times 10^{-3} \div 4 = 1 \times 10^{-3}$

4. Outage due to equipment failure (four to one ratio is allocated between equipment outage and propagation outage); $1 \times 10^{-3} \times 80\% = 8 \times 10^{-4}$

5. Outage due to propagation; $1 \times 10^{-3} \times 20\% = 2 \times 10^{-4}$

6. Outage due to propagation for 14 LOS (same unavailability is allocated to one troposcatter and 14 LOS); $2 \times 10^{-4} \div 2 = 1 \times 10^{-4}$

7. Single 48 km LOS outage due to propagation; $1 \times 10^{-4} \div 14 = 7 \times 10^{-6}$.

including equipment failure rate (Ref. 3-1), the unavailability allocation to the single 48 km LOS is 4×10^{-5} (availability 0.99996).

3.3.2.2 Millimeter Wave Radio Availability

Unlike a microwave LOS link, there is as yet no standard availability allocation for a millimeter wave radio link. Since a millimeter wave radio link may also be categorized as a LOS link, the availability for a microwave link may be transformed to that for a millimeter wave link. A millimeter wave link however, is severely affected by climatic conditions, especially heavy rainfalls which severely attenuate transmissions above 10 GHz. Thus, it is necessary to rearrange the assumption of the four to one relative ratio between equipment outage and propagation outage.

According to the reliability record specified in MIL-STD-188-XXX Appendix C (Ref. 3-1) two microwave radio sets have 3.34×10^{-5} unavailability allocation due to equipment failure. This value does not include multiplexer, trunk encryption device, station power system, or station timing system. Millimeter wave and microwave radio sets differ only in frequency. Functions and transmit power are almost identical. However, a millimeter wave link distance must be shorter than a microwave link because of the attenuation due to rainfall effect. Therefore more

repeaters are required than for a microwave link. As stated, there are two millimeter link unavailability allocation difficulties compared to a microwave link.

1. Greater propagation outage is required

2. More equipment outage is encountered because greater numbers of repeaters are needed.

However, there are two positive points for the millimeter wave link: One is that the use of the millimeter wave can reduce the number of links due to its wideband advantages; the other is that the heavy rainfall effect can be avoided by rerouting traffic, as heavy rainfall affects a very small region.

Therefore, it is tentatively suggested for a 10 km millimeter wave link that 1.8×10^{-5} and 3.5×10^{-5} be allocated to the unavailabilities for equipment and propagation respectively. As a result, the unavailability allocation to the single 10 km millimeter wave link is 5.3×10^{-5} (availability 0.99995).

3.3.2.3 Optical Fiber Availability

Since optical fiber is a cable link not experiencing atmospheric effects, any outages are long-term. The BER threshold beyond which the cable link will be considered unavailable is 1×10^{-7}, in contrast to the 1×10^{-6} value for microwave/millimeter wave links (Ref. 3-1).

The objective availability of optical fiber is a 0.99995 minimum per repeater section. Availability is the cumulative percentage of time that the optical fiber system is not in an outage condition, where outage is defined as a BER in excess of 10^{-7} for a period in excess of one minute for the end-to-end optical fiber system.

3.3.3 Mean Time to Loss of Bit Count Integrity

Reference 3-1 suggests the use of Mean Time to Loss of Bit Count Integrity (MTLBCI) as a system performance evaluator in addition to the two quality measure parameters: End-to-End (ETE) Availability, Average Bit Error Rate (BER). The MTLBCI requirement is discussed in this section.

3.3.3.1 Effects of Loss of Bit Count Integrity

The digital radio maintains synchronization for any condition where BCI is maintained. Loss of BCI, i.e., the accidental insertion of an extra bit or more bits into the bit stream or deletion of one bit or more from the bit stream, causes loss of synchronization and thus requires resynchronization. The resulting time needed for resynchronization extends the total duration of outage.

3.3.3.2 MTLBCI Requirement

Reference 3-1 requires a minimum 4,800 hours (200 days) MTLBCI for a 48 km (30 mi) length microwave LOS. While that reference did not assign MTLBCI for millimeter wave radio, a rough value can be found by the rule of thumb. Since typical millimeter wave radios are separated by 10 km, the required minimum MTLBCI is 4800 X 5 = 24,000 hours (1,000 days). Although confidence in this value is not assured, it is evident that the MTLBCI requirement is very stringent. MTLBCI requirements for digital cable link are also 4,800 hours (200 days).

3.3.3.3 Synchronous Systems

A system is defined as synchronous if between any two significant instances in the overall bit stream there is always an integral number of unit intervals. (Ref. 3-1). There are three different types of synchronous systems; slaved, pulse stuffed, and buffered synchronization. The slaved synchronous system uses a common clock source for both source and sink. The pulse stuffed synchronous system utilizes a buffer memory to add or delete extra bits in the demultiplexer. The buffered synchronous system has a large size buffer which smoothes out fluctuations of the incoming bit rate.

3.3.3.4 Loss of Bit Count Integrity

Loss of BCI may occur due to the following reasons for each of the three synchronous systems:

1. Loss of bit synchronization in slaved synchronization system. This occurs when the signal to noise ratio of the receiver becomes smaller than a threshold value maintaining synchronization. The synchronization loop, for instance, phase locked loop, loses tracking of the bit stream and causes erroneous timing bits which are used to sample the data stream. In order to strengthen the

tracking capability, the loop bandwidth must be narrow. However, the narrow loop bandwidth requires longer acquisition time to resynchronize. It is very seldom that the tracking loop loses a synchronization since a typical receiver can still maintain synchronization when the received signal strength drops down to 15-20 dB below the signal level corresponding to 10^{-4} bit error probability.

2. Buffer overflow and underflow in a buffered system. If the original bit stream and the received bit stream have the same average frequency and the difference in transmitter and receiver is bounded by some specified maximum, elastic buffer of sufficiently large size can smooth out short-term fluctuations in the bit stream. The received bit stream is fed into a buffer and then clocked out at a rate synchronous with the receiver. The buffer is sized to prevent overflow or underflow by acting as a storage reservoir. However, if the buffer does overflow, it incorrectly deletes bits from the received bit stream. On the other hand, if the buffer underflows, it also incorrectly adds unnecessary bits. Both overflow and underflow cause a loss of BCI.

3. Transmission errors in pulse (word) stuffed synchronous system. A word stuffed synchronous system is a variant of a pulse stuffed system. The pulse stuffed system has a buffer memory in the 2nd-level multiplexers with a stuffing control synchronizer which can identify the time when stuffing occurs so that bits can be added or deleted at the demultiplexer buffer. The pulse stuffed system may tolerate larger bit errors than the buffered synchronous system. Apparently, as the number of pulse stuffed words that are inserted into the transmitted bit stream increases, the more likely the receiver can prevent loss of synchronization. When the signal to noise ratio of the pulse stuffing control word in the bit stream goes down enough to make an erroneous decision to recover the control word, the receiver looses BCI. Therefore, the number of pulse stuffing control words depends on the percentage of fade outage which cause errors in the control word. In other words, transmission error depends on the coding redundancy of control word.

3.3.3.5 BCI Considerations in Phase II Study

As was explained in the previous pages, BCI depends on the synchronization schemes. It is well known that some kind of modified phase locked loop is used in bit timing recovery loop. In a typical receiver, the fraction of total LOS outages which will incur a loss of BCI due to timing recovery loss in 0.6% (Ref. 3-2). This value is so small that it contributes almost negligibly to extension of already existing fade outages.

The most common schemes employed in multiplexer/demultiplexer is the pulse stuffing synchronous system. In a dual diversity microwave LOS channel, a 9-bit stuff control word satisfies the requirement that 10% of LOS fade outage causes a loss of BCI (Ref. 3-2). In order to obtain an accurate MTLBCI value, a detailed word format is required in pulse stuffing control words that are necessary for each frame or superframe and the bit rate or stuff word rate.

As was stated in Section 3.1, the DCS III Study, Phase II involves network design includin g site selection with various transmission media, RF link parameter selection, and cost analysis. Baseband signal format as well as multiplexing/demultiplexing and switching equipment is beyond the scope of the study.

The bit timing recovery loop contributes less than 1% to the loss of BCI, and the FCC-98/FCC-99 is designed to have more than 24 hour Mean Time to Loss Of Synchronization at a received signal level as poor as that corresponding to a 10^{-2} BER, and it can resynchronize within 5 milliseconds. Therefore, the MTLBCI is not a serious obstacle in the system design as long as sufficient system margin is provided. Furthermore, BCI performance as specified by FCC-98/FCC-99 will not impact the outage time of a link and hence the link availability.

As a result, it is concluded that BCI will not be considered in the DCS III, Phase II Study beca-se of two reasons:

1. The Multiplexer/Demultiplexer is not a concern of the Phase II work

2. The MTLBCI requirement is not a restriction for parameter selection with an RF system utilizing FCC-98/FCC-99.

3.4 MEASURE OF NETWORK PERFORMANCE IN STRESSED CONDITION

Communication link performance measures in a benign environment have been presented and discussed in Section 3.3. However, there is no commonly accepted performance measure of a complex communications network in a stressed condition. In Phase II guidance, a measure of average network availability (ANA) is suggested but not defined. In this section, the stressed condition is explained first and the ANA is defined and discussed. Then related assumptions which are adopted for the ANA evaluation are presented.

3.4.1 Stressed Condition

There are many different kinds of threats which an enemy may apply to a communications link or network, for example, jamming, high altitude electromagnetic pulse (HEMP) attack, and various forms of physical attacks on a communications facility. Because of the difficulties of defining a threat scenario, and then analyzing the impact of the scenario on the communications systems, a stressed condition will be represented by the deletion of transmission links from the communications network. If a node is attacked, all links connected to that node will be removed from the network.

The guidance specifies that the network performance will be evaluated by random disruption of 10, 20, and 50 percent of all links.

3.4.2 Average Network Availability

Although "link availability" or average link availability can be defined in several different ways, by adopting a definition, the performance of a link can be computed or predicated theoretically or measured. Average network availability is a new concept which does not yet have a commonly accepted definition. In the context of the present work, ANA is defined in the following paragraph.

All links of a network under consideration have a known capacities in terms of number of voice channels or bit rate expressed in Mbps. A digitized voice channel is counted as 64 kbps. Each link has a 20 percent growth capacity or spare capacity if not specified, which will be used to reroute traffic in the most efficient way. Each link of the network also assumes a prorated link time availability (LTA) as discussed in the

previous section. Each node contains the necessary multiplexer-demultiplexer and switching device for automatic traffic rerouting.

In a stressed condition with some randomly selected links having been removed, all surviving links are assumed to perform at least equal to or better than their specified LTA. Then all spare link capacities of surviving links will be used to reroute traffics of the disrupted links.

With the above assumptions in mind, then measures or terms are defined. To be specific, consider a network consisting of n nodes and l links. Let N_i, $i = 1, 2, ..., n$ and L_j or $L_j (h, k)$, $j = 1, 2, . . . l$, denote these nodes and links respectively where h and k are the nodes, namely N_h and N_k connected by the L_j link. The link traffic and spare capacity of L_j link are denoted by LT_j and LS_j both in terms of number of voice channels or data rate in Mbps. To simulate a stressed condition, a r-percent of number of links of the network, i.e.,

$$m = rn \quad \text{(an integer)}$$

be deleted. Let these deleted links be $M_p(q,t)$ and their link traffic and spare capacity be MT_p and MS_p. Then the Total Disrupted Link Traffic of the network is the summation of link traffic of all disrupted links, i.e.,

$$TDLT = \sum_p MT_p \quad .$$

The Network Traffic Disruption Rate (NTDR) is the fraction of link traffic being disrupted and is given by

$$NTDR = \frac{\sum_p MT_p}{\sum_j LT_j} \quad .$$

Apparently, NTDR does not equal to r in general. Not all disrupted link traffic, TDLT, is lost because part of the disrupted link traffic would be rerouted through the spare capacities of other surviving links. The rerouted traffic for the disrupted link M_p is expressed as

$$RT_p = RT_{p1} + RT_{p2} + \cdots$$

Where RT_{p1}, RT_{p2}, . . . denote rerouted traffic through 1-relay, 2-relay,. . . respectively. Then the Total Rerouted Link Traffic (TRLT) is

$$TRLT = \sum_{p} RTp = \sum_{p} RTp1 + \sum_{p} RTp2 + \ldots \ldots$$

The Network Traffic Reduction Rate (NTRR) is defined by

$$NTRR = \frac{\sum_{p} MTp - \sum_{p} RTp}{\sum_{j} LTj}$$

and gives the fraction of the net lost traffic.

Then the Network Availability for this specified condition is defined by

$$NA = \frac{\sum_{s} (LTs)(LTA) + \sum_{p} (RTp1)(LTA) + \sum_{p} (RTp2)(LTA)2 + \ldots}{\sum_{j} (LTj)(LTA)}$$

Where index s indicates all surviving links of the network. The above definition of NA assumes the same LTA for all links, otherwise, the corresponding LTAs will be used for the involved links.

The Average Network Availability (ANA) is the average of all NAs obtained by enough numbers of replications of the Monte Carlo method of deleting r-percent of total number of links.

Computing the ANA as defined above cannot be done manually because of the following reasons:

1. Search, identify, and record rerouting paths for even one link of a moderate sized network is a time consuming process.

2. Utilization of the Monte Carlo method to select links to be deleted implies the use of a random number generator.

3. The number of replications to provide statistically significant results of ANA is large. For example, for a moderate sized network consisting of 50 links, there is a total number of 126 trillion ways, 126,410,606,437,752 to be exact, to select 25 deleted links. Therefore, a computer program needs to be developed. This program would continuously update the current ANA each time with a new NA generated by replication of the Monte Carlo method. This process would stop automatically

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until the updated ANA stabilized or the changes of successful ANAs are smaller than a specified limit. At this time, based on the partially developed program, the flow diagram of the complete code is envisioned as shown in Figure 3-2.

3.4.3 Related Assumptions and Remarks

It should be pointed out that the ANA so defined is for the purpose of comparing effectiveness of various proposed transmission alternatives under a specified stressed environment. Since a Monte Carlo method is utilized, to select deleted links the defined ANA is meaningful only for a complex network with a very large number of links and enough number of Monte Carlo replications on NA evaluations.

Some major assumptions of this suggested definition of ANA are listed below, some of them had already been discussed in the last section.

1. Each link is assumed with a known link traffic, spare capacity, and link time availability

2. In a stressed condition, the spare capacity of surving links will be used for rerouting the traffic of disrupted links

3. Automatic rerouting, switching, multiplexer and demultiplexer equipment for rerouting traffic are assumed for each node

4. All traffic is assumed to have equal priority.

It is seen that network availability of a transmission alternative depends on the following factors:

● Network topology

● Link traffic and spare capacity of each link

● Particular links assumed to be disrupted.

Furthermore, optimizing rerouting will provide the following information:

● Bottleneck of each rerouting path

● Links competed by different rerouting paths for one disrupted link

● Links competed by rerouting path for two or more disruption links.

The above information is crucial for modifying the network. An interactive computer program can be further developed, based on the ANA evaluation program mentioned already, to mechanize the process of improving network survivability. Figure 3-3 depicts such an interactive program.
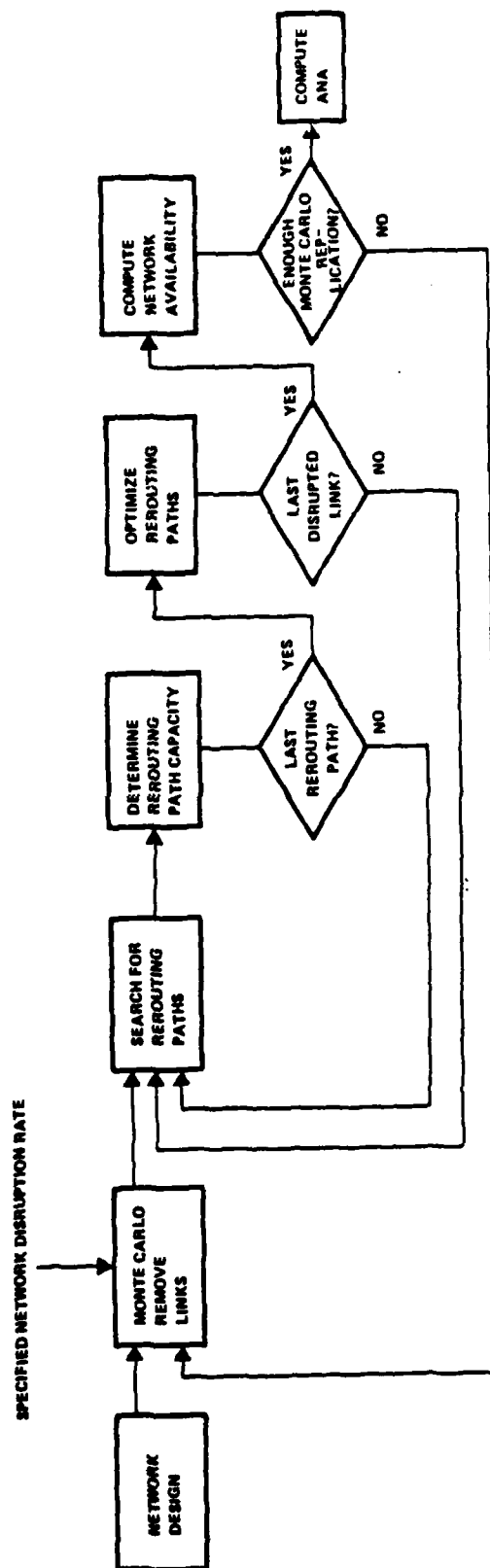
Figure 3-2   Flow Diagram of ANA Computing Program
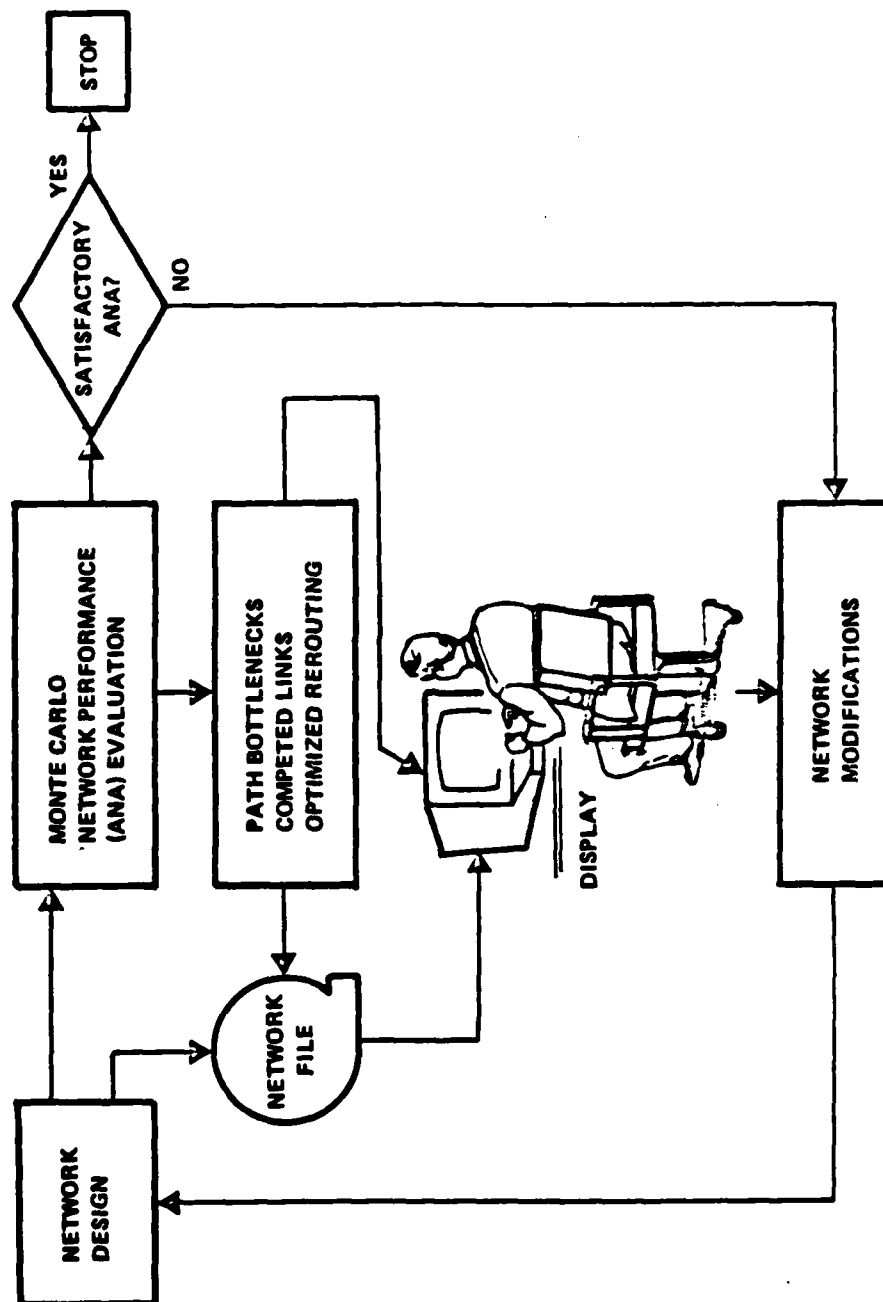
Figure 3-3 Flow Diagram of an Interactive Network Design Program

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4.0 RF TRANSMISSION SYSTEM MODELS

This section presents a developed RF transmission system model for each of the three transmission media considered in this Task, namely microwave line-of-sight, millimeter wave line-of-sight system, and fiber optics system.

Block diagrams of typical transmission equipment are developed and discussed here. Also equipment parameters and specifications are defined based on current state-of-the-art and the expected one in the year 2000.

Based upon the current trends in transmission of information it is anticipated that by the year 2000 all systems implemented will be digital for both data and voice traffic. The voice digital conversion rate is assumed to be 64 kbps in accordance with the FCC-98 and FCC-99 multiplexer-demultiplexer scheme.

4.1 MICROWAVE TRANSMISSION SYSTEM

Microwave line-of-sight applications are the furthest advanced of the three transmission media. Presently frequency division multiplex systems are predominant, however, it is expected that by the year 2000 all transmission systems will be exclusively digital. Only digital radio is considered in this model.

It is predicted that with new and improved modulation methods digital radios will become increasingly bandwidth efficient. Therefore, a radio capable of transmitting and receiving 120 Mbps signal or equivalent per RF channel could be considered for the future, provided a 30 MHz bandwidth were available. Since the present authorized bandwidth is 14 MHz the model considered will be capable of transmitting and receiving 52.096 Mbps employing 4 bps/Hz modulation scheme.

Multipath fading occurs to some degree on most microwave line-of-sight paths. In addition to the various diversity systems which can be used to combat fading recently developed adaptive equalizers, helping to minimize the resultant intersymbol interference, are also considered in the modeling.

The equipment model will consider the currently used 4.4-5.0 GHz and 7.125-8.4 GHz frequency bands. In each band the duplex channel separation will be at least 80 MHz and in the case of frequency diversity each transmitter will be separated by at least 100 MHz.

In the area of hardware implementation, the current state-of-the-art is considered along with the evolving Large Scale Integration (LSI), Very Large Scale Integration (VLSI), and solid state power amplifier, etc.

4.1.1 Microwave Radio Characteristics and Components

The choice of modulation techniques and ultimate system capacity are interrelated. The mode considered will be single polarization and will interface at 52.096 Mbps data rate (equivalent to 768 voice channels). It is predicted that a 16 level QAM technique providing 4 bps/Hz bit rate bandwidth efficiency will be in use by the year 2000. It is assumed that the proposed radio can either accept a bit stream of FCC-99 second level multiplexer directly or through a third level multiplexer. Multiplexers will not be addressed in the present work.

It is predicted that the Traveling-Wave Tube (TWT) will be replaced by a solid state power amplifier such as a Gallium Arsenide (GaAs) Field Effect Transistor (FET) which will deliver two watts or more. This device can be directly modulated by varying the supply voltage or bias. It exhibits good linearity over a wide frequency band and offers high reliability.

The radio equipment will be configured for either space diversity or frequency diversity, depending upon propagation conditions. The space diversity arrangement with hot standby transmitters (Figure 4-1, 4-2) provides equipment redundancy but does not provide separate end-to-end paths. It does, however, provide efficient frequency spectrum usage. The frequency diversity arrangement (Figures 4-3, 4-4) provides equipment redundancy and the operational advantage of two independent paths. Thus, testing may be performed without system outages. Its disadvantage is, however, that it uses additional frequency spectrum. Since it is important to retain the bit count integrity (BCI) it is desirable to provide hitless diversity switching. Switching on a 1:1 hop basis will be provided.
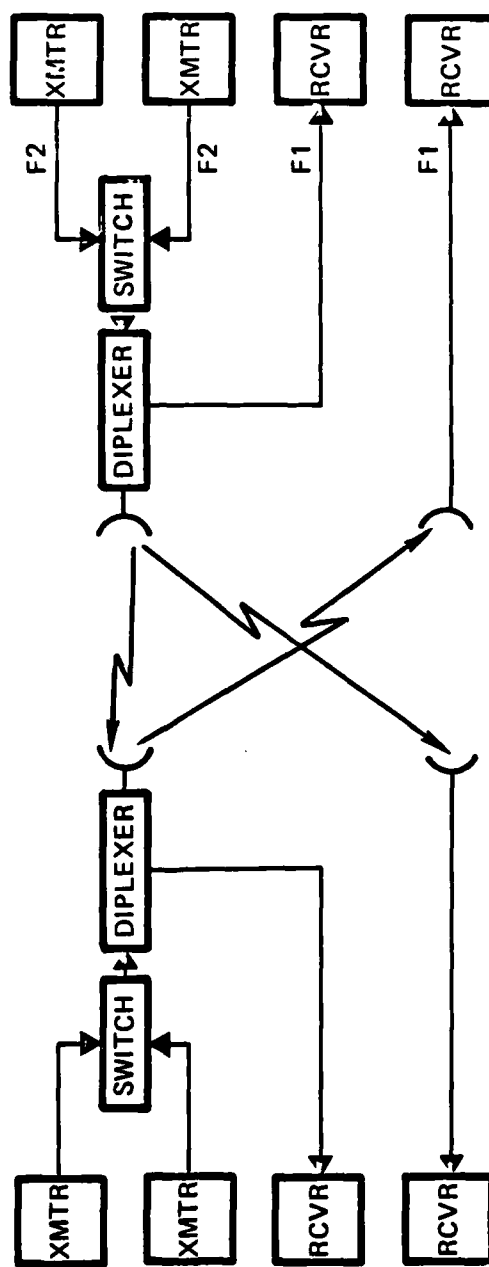
Figure 4-1 Space Diversity System with Hot Standby Transmitter
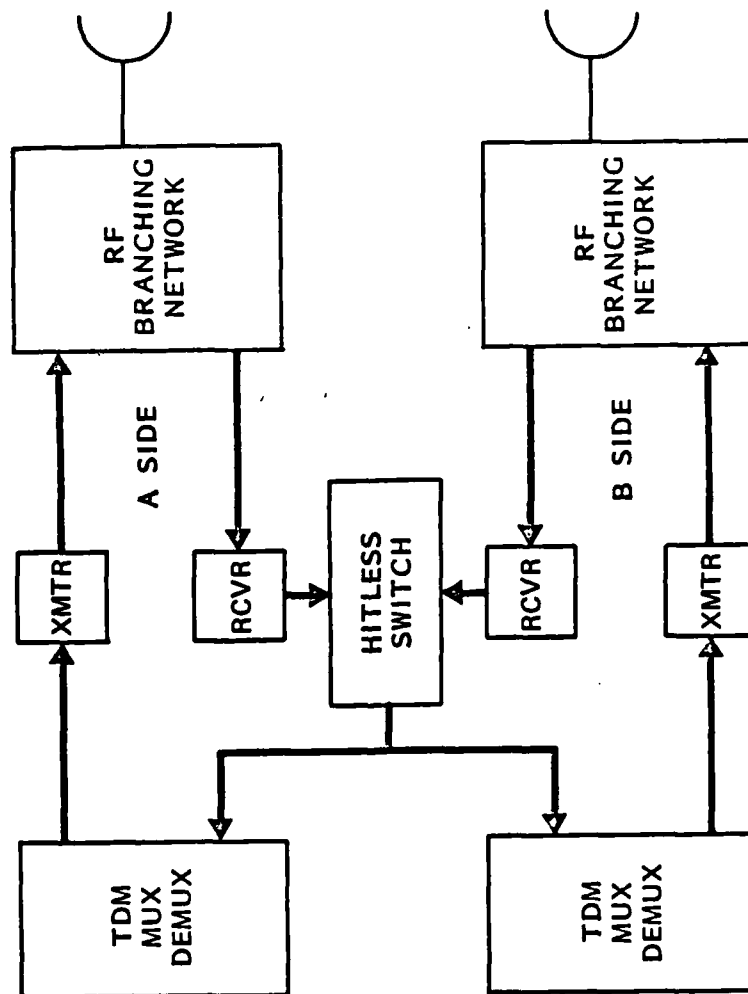
Figure 4-2 Space Diversity Terminal Block Diagram
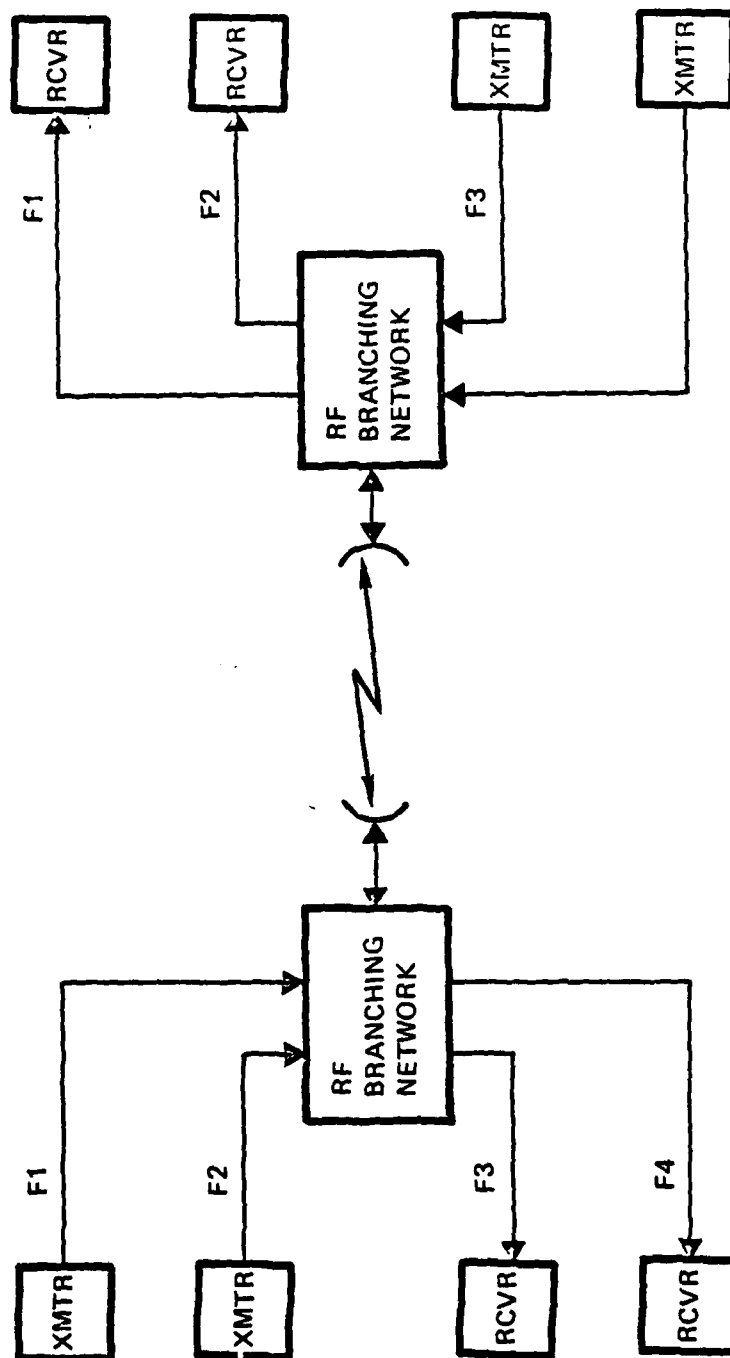
Figure 4-3 Frequency Diversity System (Single Antenna)
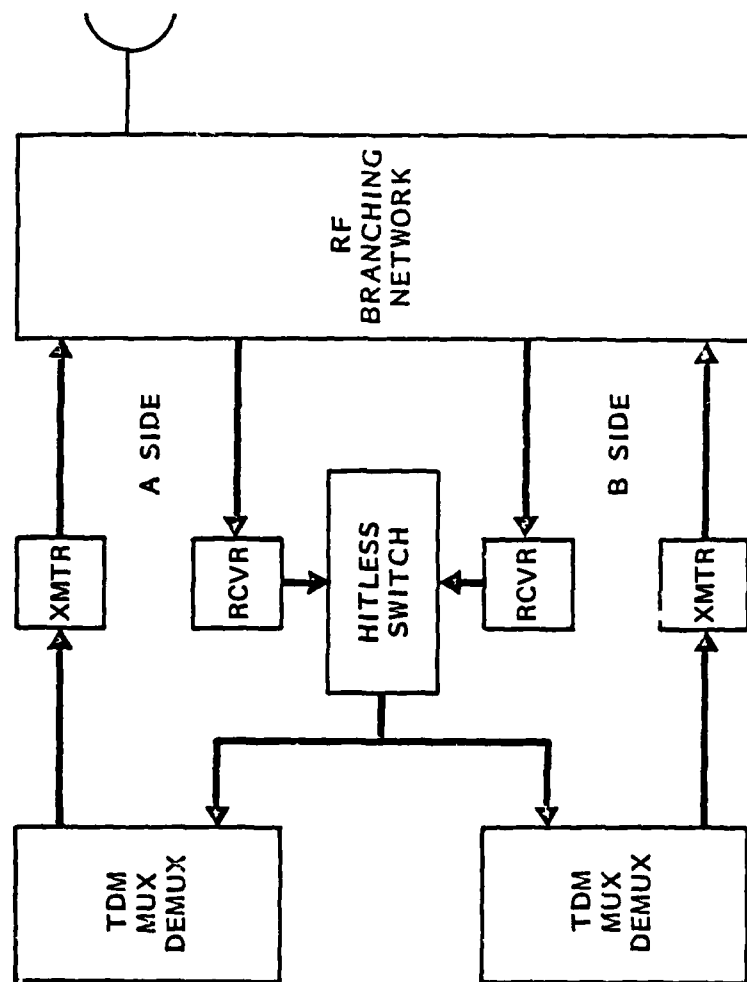
Figure 4-4   Frequency Diversity Terminal Block Diagram

4.1.2 Microwave Radio System Model

A single model cannot adequately characterize all conceivable systems, however, the system will be broken into the major generic elements. Figure 4-5 illustrates the functional elements of a microwave line-of-sight system. The block diagram for the radio is shown in Figures 4-6 and 4-7.

In a digital microwave LOS radio system, the bit error rate during multipath fading periods is controlled by intersymbol interference resulting from frequency dependent amplitude distortion and group delay effects. As the data rate and bandwidth efficiency increases, the distortion effects of multipath have become an increasingly serious problem. The effects of multipath on PSK digital systems have been verified by empirical data collected on a number of operating systems. It has been verified that amplitude distortion caused by multipath fading and not flat-fade margin is the major factor in performance degradation. Adaptive amplitude and phase equalizers are presently employed in some operational systems to improve system performance during severe fading environment. It is expected, however, that by the year 2000 all systems will be equipped with adaptive equalizers.

In most microwave systems there is a need to transmit functions such as fault alarms, orderwire and control functions on the same radio channel as the message traffic. This need will increase with the increase in centralized system monitoring and control. The technique for inserting the auxiliary channels will minimize the degradation of the traffic bit stream. It is envisioned that six 64 kbps channels for service will be sufficient.

Where drop and insert capabilities are required, it will not be necessary to convert the whole bit stream to the drop and insert level. In the model which carries one 52.096 Mbps bit stream, it is necessary to convert this bit stream to one level (two 12.928 Mbps) bit stream plus

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DATA ACQUISITION
- MULTIPLEXERS
- FROMATTING
- AUXILIARY CHANNEL

DATA CONDITIONING
- ENCODING
- SIGNAL CONDITIONING
- MODULATION

TRANSMITTER
- MODULATION
- FREQUENCY SYNTHESIES
- UPCONVERSION
- POWER AMPLIFIER
- FILTERING

ANTENNA
- GAIN AND PATTERN
- FEEDER
- TOWER
- MOUNTING

RECEIVER
- LOW NOISE AMPLIFIER
- FILTERING
- FREQUENCY SYNTHESIS
- DOWN CONVERSION
- MIXER
- ADAPTIVE EQUALIZATION

SIGNAL PROCESSING
- DEMODULATION
- DECODING
- DEMULTIPLEXERS

Figure 4-5 Microwave LOS System Basic Elements

4-8
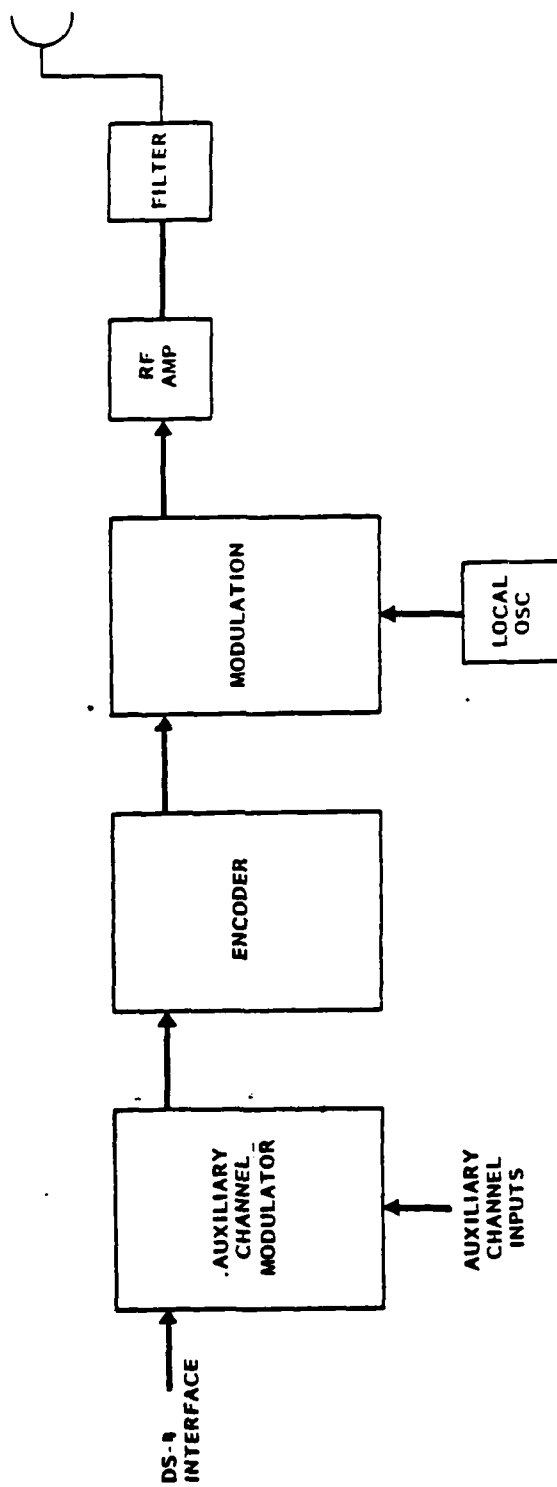
Figure 4-6   Transmitter Block Diagram
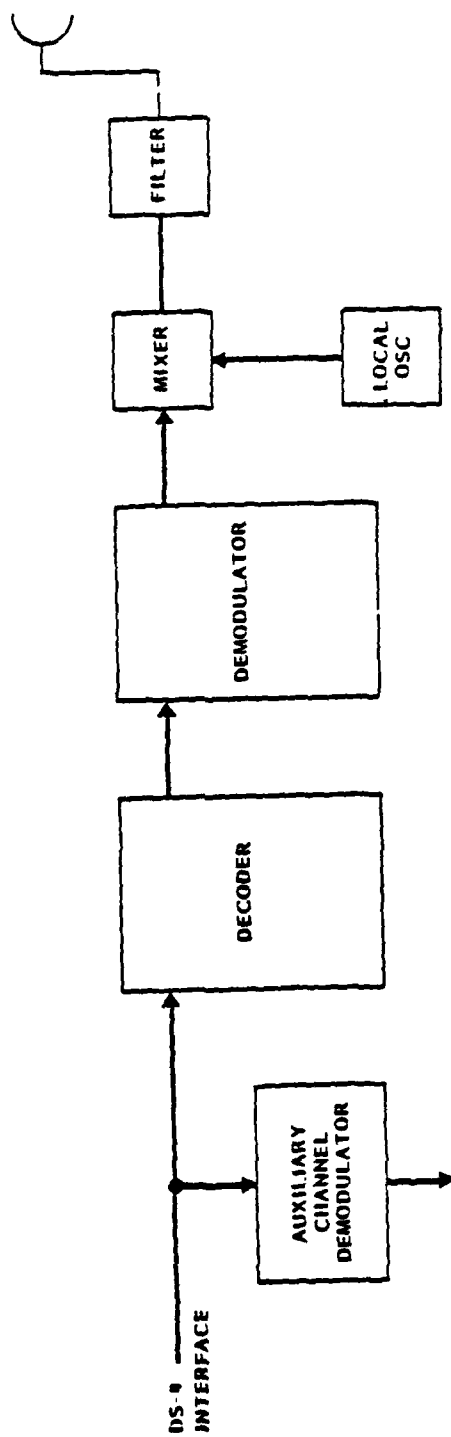
Figure 4-7 Receiver Block Diagram

one service bit. The other three level two-bit streams are connected through the repeater and combined with the inserted bit streams and service channel to the 52.096 Mbps level. Any one or all of the T1 bit streams may be dropped or inserted. However, for a repeater station, if the required drop and/or insert is more than one level two channel equivalent, then the other level two-bit streams can be broken down for drop and insert purpose. There is no difficulty to do the drop or insert at the level required but Figure 4-8 only shows the drop and insert at one level two level.

4.1.3 Microwave Equipment Specification

The microwave line-of-sight RF equipment specification of the year 2000 envisioned at the present time is given in Table 4-1.

4.1.4 Ancillary Equipment

This section contains specifications of needed equipment other than basic radio equipment listed in Section 4.1.3.

1. Antennas

   For purpose other than tower wind loading eight-foot shrouded parabolic antennas in a space diversity configuration are considered. No significant changes are expected between the present and the year 2000.

2. Antenna Towers

   The tower height and type depend upon the installation configuration i.e., terminal, junction and path clearance required, etc. for the purposes of this model a self-supporting tower capable of withstanding the windloading of four ten-foot shrouded antenna will be considered. The height of the tower is limited to 100 meters.

3. Waveguide

   Low loss extruded aluminum or corrugated copper rectangular or elliptical waveguide is considered for this model for outdoor use.

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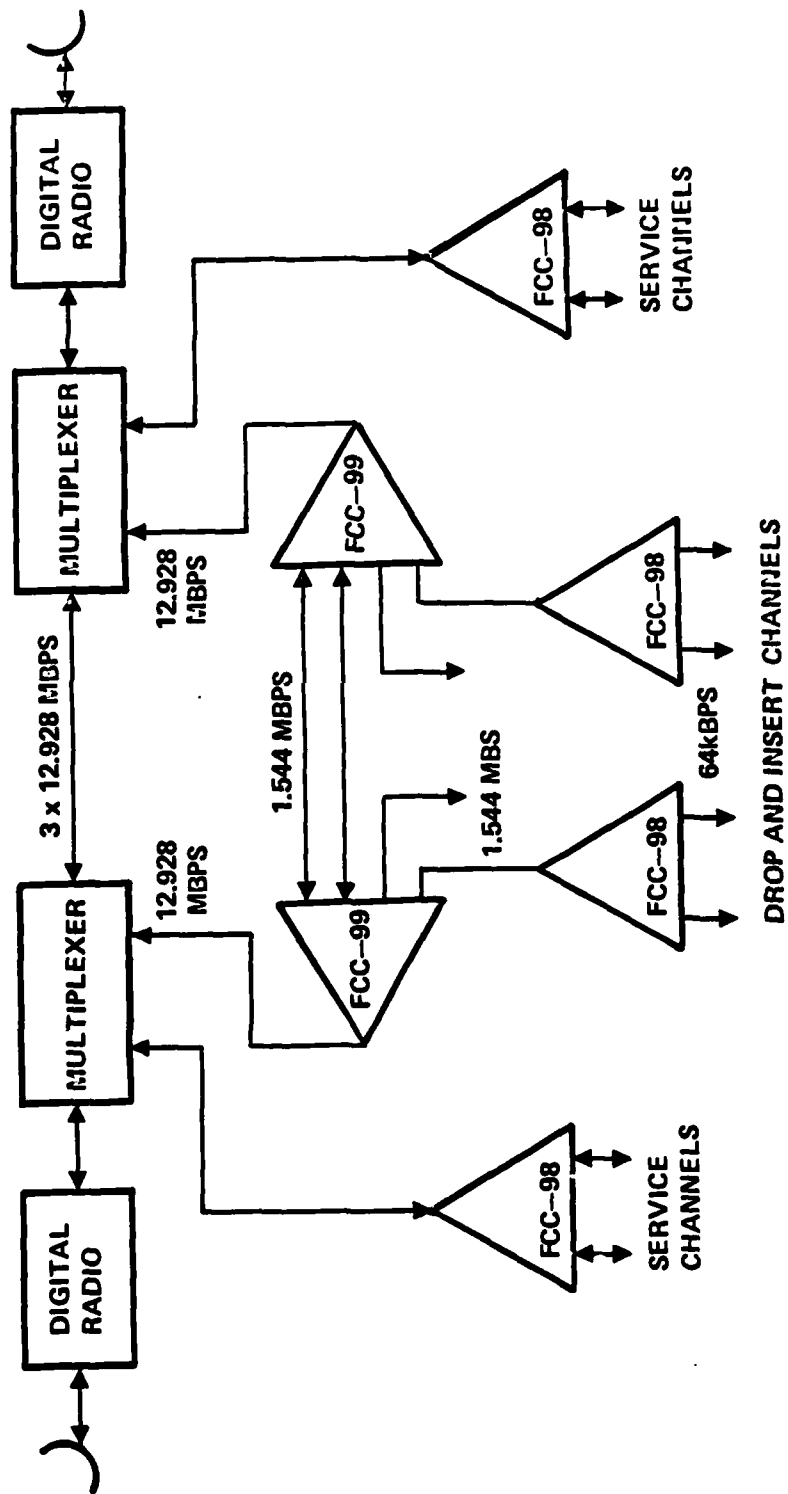
Figure 4-8. Microwave Line-of-Sight Repeater With Drop and Insert

TABLE 4-1. SPECIFICATION OF MICROWAVE LOS SYSTEM

Transmitter	
RF Power Output	2 Watts
Emission Bandwidth	14 MHz
Frequency	8 GHZ
Frequency Stability	$\pm$.0005% 0°C to 40°C
Modulation	16 Level QAM
Receiver	
Noise Figure	5 dB
S/N at 10^{-9} BER	24 dB
Dynamic Range Threshold 10^{-6} BER	-68 dBm
10^{-3} BER	-72 dBm
Data Interface Cha acteristics	
Channel Capacity	768 Voice Channels
Transmission Bit Rate	52.096 Mbps $\pm$ 20 ppm
Frequency Utilization Efficiency	4 bps/Hz
Data Streams	Bipolar, B3ZS
Auxiliary Channels	384 kbps
Impedance	75 ohm $\pm$ 5%
Power Level	-1.8 to + 5.7 dBm
Power	
Input Voltage	-24/48 vdc
Terminal Current Consumption	40/20 AMP/BAY
Repeater Current Consumption	70/35 AMP/BAY

TABLE 4-1.   SPECIFICATION OF MICROWAVE LOS SYSTEM (CONTINUED)

Operating Environment	
Temperature	0° to 49° C
Altitude	0 to 4572 m
Humidity	0 to 95%
EMI	MIL-STD-461
Physical Characteristics	
Terminal	521 X 225 X 2133 mm
	70 Kg
Repeater	1042 X 225 X 2133 mm
	140 Kg

Alarm   Upon occurence of any one or more of the following malfunctions or conditions, an alarm will be reported at both terminals.

Transmitter:	Receiver:
All input data/timing	All output data/timing
Buffer overflow/underflow	Buffer overflow/underflow
Modulation output	Demodulator output
Oscillator frequency draft	Frame sync loss
Output power	Low frame BER
Online/offline status	Oscillator frequency draft
External/internal timing	Online/offline status
Power Supply Voltage Level	

4. D. C. Power Plant

Reliable power is essential in a communication system. The
equipment will be operated from -24/48 volt DC thus
lending itself to battery operation. The battery charger, -
therefore, will be powered by AC. The AC will be supplied
either from the local power network or, if not available, from
dedicated generators. The battery plant will have the capacity
to supply power to the equipment, in the event of failure of
the AC power, for a period of at least eight hours. Significant
developments in battery design are expected by the year 2000.
Batteries will be more efficient, therefore, will be smaller
for the same storage capacity.

5. Test Equipment

It is predicated that the equipment will include Built-In-Test-
Equipment (BITE) to provide remote monitoring and testing.

4.2 MILLIMETER WAVE TRANSMISSION SYSTEM

Millimeter wave radio is not a new development but up to the present
has seen very limited use. However, despite the range limitations
imposed by weather, the ever-increasing demand for new spectral space,
coupled with advances in technology, the future looks promising for the
development of mm-wave line-of-sight communication systems.

Equipment operating in the 38 GHz band presently does exist for
handling 1.544 Mbps and 20 Mbps transmission rates. The advantages of
millimeter wave radios are small size, light weight, low intercept and
jamming probability. Although wide bandwidths are available in the
millimeter wave spectrum which would allow for high speed data trans-
mission (247,400 Mbps, etc.) consideration is given only for application
to short spur routes.

4.2.1 Millimeter Wave Radio Characteristics and Components

Semiconductor devices such as FET's IMPATT and GUN (TED) as
discussed in a previous study, all show merit when used as a low power
source. They all can be modulated directly by varying the supply voltage
or bias.

4-15

It is predicated that by 1990 the noise figures and instantaneous bandwidths possible in mm-wave receivers will be similar to those of early 1970's microwave receivers.

Microwave integrated circuit (MIC) technology currently is adequate for fabricating small assemblies of complex systems built around mm-wave semiconductor devices. Antennas of various types which cover the millimeter wave band are presently on the market.

Use of MIC hybrid circuits approaches to millimeter wave radio design forms a base technology capability that provides long-term advantages including:

- Application to the next generation monolithic device technology

- Applicability to MIC filter, oscillator, and antenna fabrication for future use in monolithic integrated circuits.

- Also the use of millimeter MIC receivers with integral FET IF amplifiers will become commonplace.

It is predicted that solid state amplifiers such as IMPATT amplifiers which will deliver two watts will be utilized in the year 2000. This is a multistage device whose output goes to zero when the input goes to zero. Should any one diode fail, the reduction in output power will be approximately equal to the loss of gain of that stage.

4.2.2 Millimeter Wave Radio System Model

A simplified block diagram, Figure 4-9, illustrates a millimeter wave line-of-sight system. The functional elements of a microwave line-of-sight system shown in Figure 4-5 also applies to a millimeter wave system.

A typical mm-wave line-of-sight system designed for this study will carry up to 52 Mbps. This would be in a hot standby configuration housed in a weatherproof container with an antenna radome, pole or tower mounted. This would eliminate high RF transmission line losses.

4-16
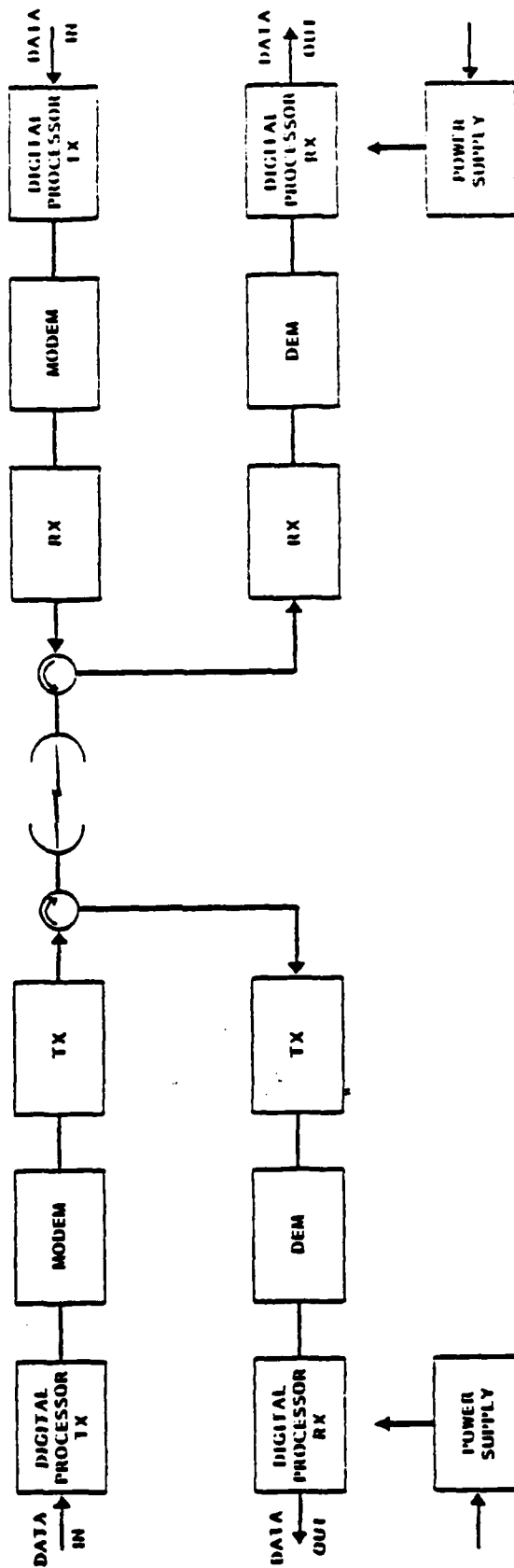
Figure 4-9 Millimeter Wave LOS System

4.2.3 Millimeter Wave Equipment Specification

A millimeter wave line-of-sight radio capable of support DS-4 level (274.176 Mbps) transmission could be designed or be available in the year 2000. Specification of a system model for this study envisioned at this time is given in Table 4-2.

Equipment redundancy is considered, however, space and/or frequency diversity are not considered, as the major factor in the link availability is rain attenuation which is not affected by the usual antenna distance used for space diversity and is not frequency selective.

4.2.4 Millimeter Wave Ancillary Equipment

This section contains the major equipment other than the radio and antenna.

1. Mounting

    The radio assembly and antenna(s) will be mounted as a unit. Due to the narrow beamwidth of the antenna it is essential that the mounting structure be limited in its twist and sway motion.

2. Power

    Terminals can be powered from locally generated power. Repeaters may be either fed from the local power source or may be operated from a solar cell power source.

4.3 OPTICAL FIBER TRANSMISSION SYSTEM

Fiber optics technology is currently at an early point on the maturation curve, however, major advances by the year 2000 will have impact on this projected DCS III alternatives. The impact will be measured in terms not only of system performance parameters, but also cost, and ease of installation and maintenance. The following discussion briefly outlines the basis of our projections of technology.

Current transmitters and receivers, and their associated circuitry are being produced in relatively small quantities, and are implemented

TABLE 4-2.   SPECIFICATION OF A MILLIMETER
WAVE LOS SYSTEM

Transmitter	
RF Power Output	2 Watts
Emission Bandwidth	17.4 MHz
Frequency	36 GHz
Modulation	8 PSK
Receiver	
Noise Figure	5 dB
S/N at 10^{-9} BER	21.5 dB
Threshold 10^{-3} BER	-77.3 dBm
Data Interface	
Channel Capacity	768 Voice Channels
Transmission Bit Rate	51.712 Mbps $\pm$ 20 ppm
Frequency Utilization Efficiency	3 bps/Hz
Data Stream	Bipolar, B3ZS
Auxiliary Channels	384 kbps
Power Level	-1.8 to + 5.7 dBm
Power Supply	
Voltage	-24/48 vdc
Consumption	50 Watts

TABLE 4-2. SPECIFICATION OF A MILLIMETER
WAVE LOS SYSTEM (CONTINUED)

Operating Environment	
Temperature	0° to 50° C
Altitude	0 to 4572 m
Humidity	0% to 95%
EMI	MIL-STD-461
Physical Characteristics	
Weight	25 kg

Alarm Upon occurence of any one or more of the following malfunctions or conditions, an alarm will be reported at both terminals.

Transmitter:	Receiver:
All input data/timing	All output data/timing
Buffer overflow/underflow	Buffer overflow/underflow
Modulation output	Demodulator output
Oscillator frequency draft	Frame sync loss
Output power	Low frame BER
Online/offline status	Oscillator frequency draft
External/internal timing	Online/offline status
Power Supply Voltage Level	

with discrete components particularly in the analog portions. Well before the year 2000, integration of these units will occur. Multiple emitters (e.g., injection-diode lasers) and detectors (e.g., avalanche photodiodes) will be available in monolithic packages. Initial development work to this end is already known to be underway in Bell Laboratories, GTE, NEC, Philips Research Labs and Siemens. The net result will be a decrease in size and cost, and an increase in reliability. For example, the projected MTBF of a link is 200,000 hours.

By analogy with the experience curves for both digital and analog integrated circuitry, a decrease in cost by a factor of 20, over the next 20 years, can be conservatively projected. Further supporting this estimate are the economies of scale to be realized by the greatly increased production quantities projected for these units.

Operating parameters foreseen for the future are based on current advanced work. Present-day fiber optic systems operate in the region of 850 nm wavelength, largely determined by the characteristics of early emitters. It is now well known that fiber losses and material dispersion are much lower when operated at wavelengths in the vicinity of 1.3 microns. At the wavelength, repeaterless transmission has already been demonstrated at 45 Mbps over a span of 55 km. Such performance will be standard by the year 2000. Since all individual links in both Central Germany and Hawaii are less than this distance, no repeaters have been incorporated in the network designs.

Concomitant with the adoption of longer wavelength transmission, it is anticipated that the present trend toward monomode fibers will continue. One result is that modal dispersion will be minimized (theoretically reduced to zero), thus allowing transmission of an extremely large bandwidth. Matching optical devices, such as bidirectional couplers, will be commonly available.

The cable to be used is made up with an integral armor sheathing, and is reinforced and water tight. Thus, the cable is suitable for direct burial. It is assumed, however, that 50 percent of the cable runs will

transit areas where additional PVC duct is necessary for pulling and/or for additional protection, and that some portions will be best installed by the aerial method.

4.3.1 Optical Fiber System Characteristics and Components

An optical fiber communication system consists of the following major components:

1. Light Source

2. Light Detector

3. Transmission medium - Optical fiber.

The available emitters can be classified as coherent and incoherent. Inject Laser Diodes (ILD) which are coherent emitters provide a high degree of spectral purity and near perfect beam collimation as well as large power densities. Light emitting diodes (LED) are incoherent emitters. They are lower powered than the laser, but provide greater spectral width. The ILD exhibits a significantly larger modulation bandwidth than does the LED. However, ILD's have much narrower spectral widths than LED's.

Light detectors for fiber optic communication systems should have the following characteristics:

- High responsitivity or quantum efficiency for the incident optical signal (sensitivity to low level light signals)

- Sufficient bandwidth

- Minimum noise added by the detection process.

There are three types of light detectors or photodetectors, namely, PN photodiode, PIN photodiode and avalanche photodiode. The avalanche photodiode (APD) appears to be the best choice for signal detection. A variety of APD structures are presently under development which provide the correct energy gap offer high speed response, and are sensitive to the 1.3 μm wave length.

Three kinds of optical fibers are currently in use. They are single mode step-index, multimode step index, and graded index fiber.

A single-mode fiber has very wide bandwidth capability with well
defined propagation characteristics. It is ideally suited for long-haul
wide band transmission. Therefore, this type of fiber will be considered
as that which will be used in systems installed in the year 2000. However,
a graded index multimode fiber, because it exhibits low coupling losses,
may still be used for short haul moderate bandwidth applications.

The parameters affecting the transmission characteristics of optical
cables are: attenuation, pulse dispersion, and numerical aperture.

Attenuation, measured in dB/km results from absorption, scattering,
and radiation losses.

Pulse dispersion or pulse spreading is the measure of the broadening
or lengthening of the light pulses as they travel along a fiber. It
is expressed in terms of nanosecond per kilometer. Pulse dispersion
limits the useful transmission bandwidth or distance along a fiber. This
pulse lengthening is caused by material dispersion, due to the frequency
dependence of the refractive index, modal dispersion, caused by different
group velocities of the different modes, and waveguide dispersion due to
frequency dependence of the propagation constant of that mode. Specific
causes include surface roughness, presence of scattering centers, bends in
the guiding structure, deformation of the guide and inhomogeneities of the
guiding medium.

The Numerical Aperture (NA) is a measure of the light collecting
capability of an optical fiber and is a function of the difference in the
refractive indices of the fiber core and cladding. The larger the NA, the
more light enters the fiber. However, attenuation increases (due to
scattering) and bandwidth is decreased as the NA is increased.

4.3.2 Optical Fiber Transmission System Model

Figure 4-10 illustrates the major generic elements of a fiber optic
communications system. The envisioned fiber system in the year 2000 is
capable of transmitting a very large bandwidth signal, DS-4 level at
276.176 Mbps or higher, over a medium distance, one hundred kilometers or
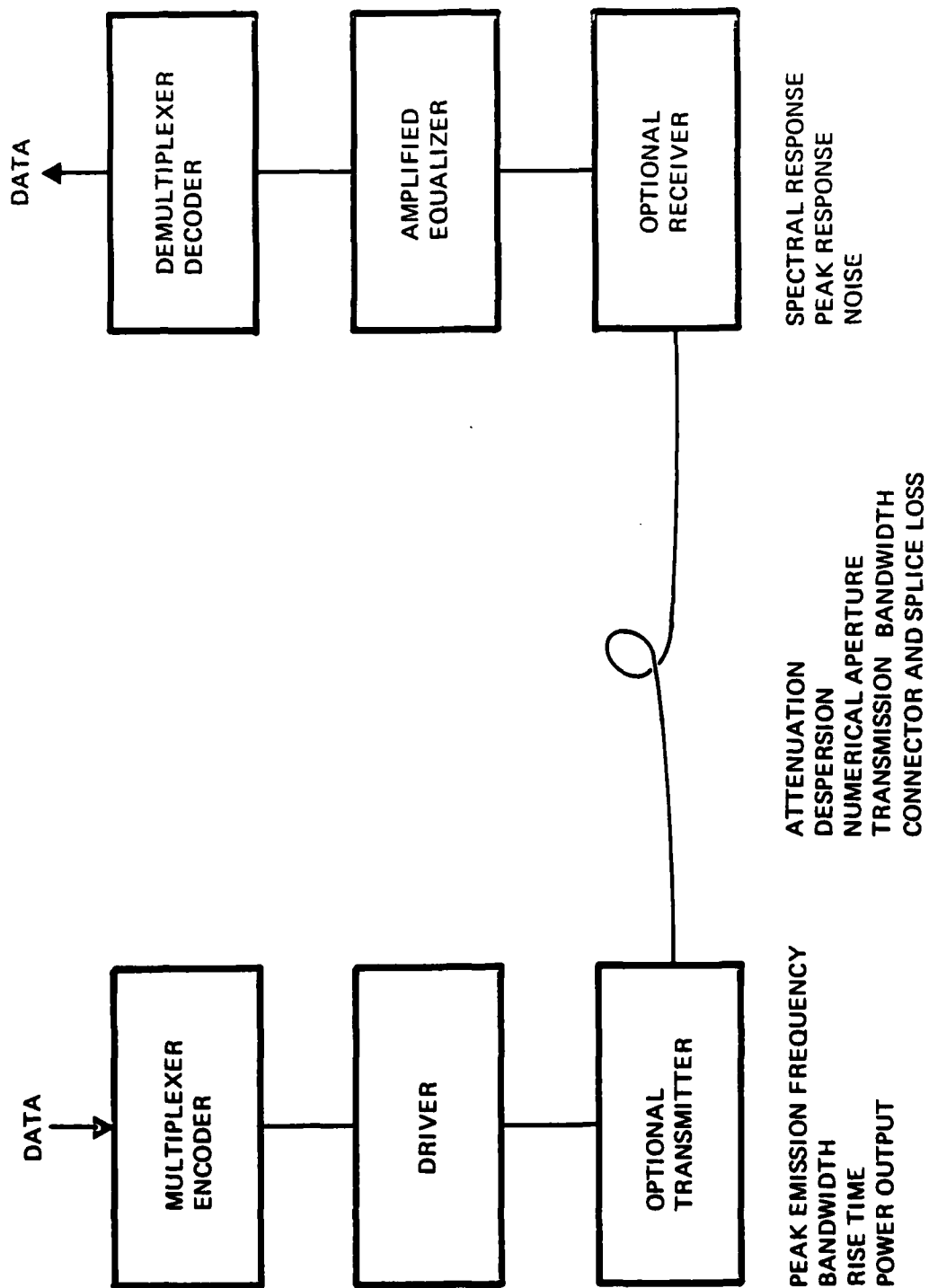
Figure 4-10 Optical Fiber System Basic Elements

so, without repeater. However, the proposed model is consistent with the
microwave and millimeter wave systems operating at an information data
rate of 52.096 Mbps. A modulation scheme with one bps/Hz efficiency is
recommended which makes the system less complex than one using higher
bit-rate-per-Hertz efficient modulator.

4.3.3 Optical Fiber System Specification

Figure 4-11 shows a simplified block diagram of a multifiber,
repeaterless system. The maximum span at the assumed optical pulse rate
is about 50-100 km. The system specification is given in Table 4-3.
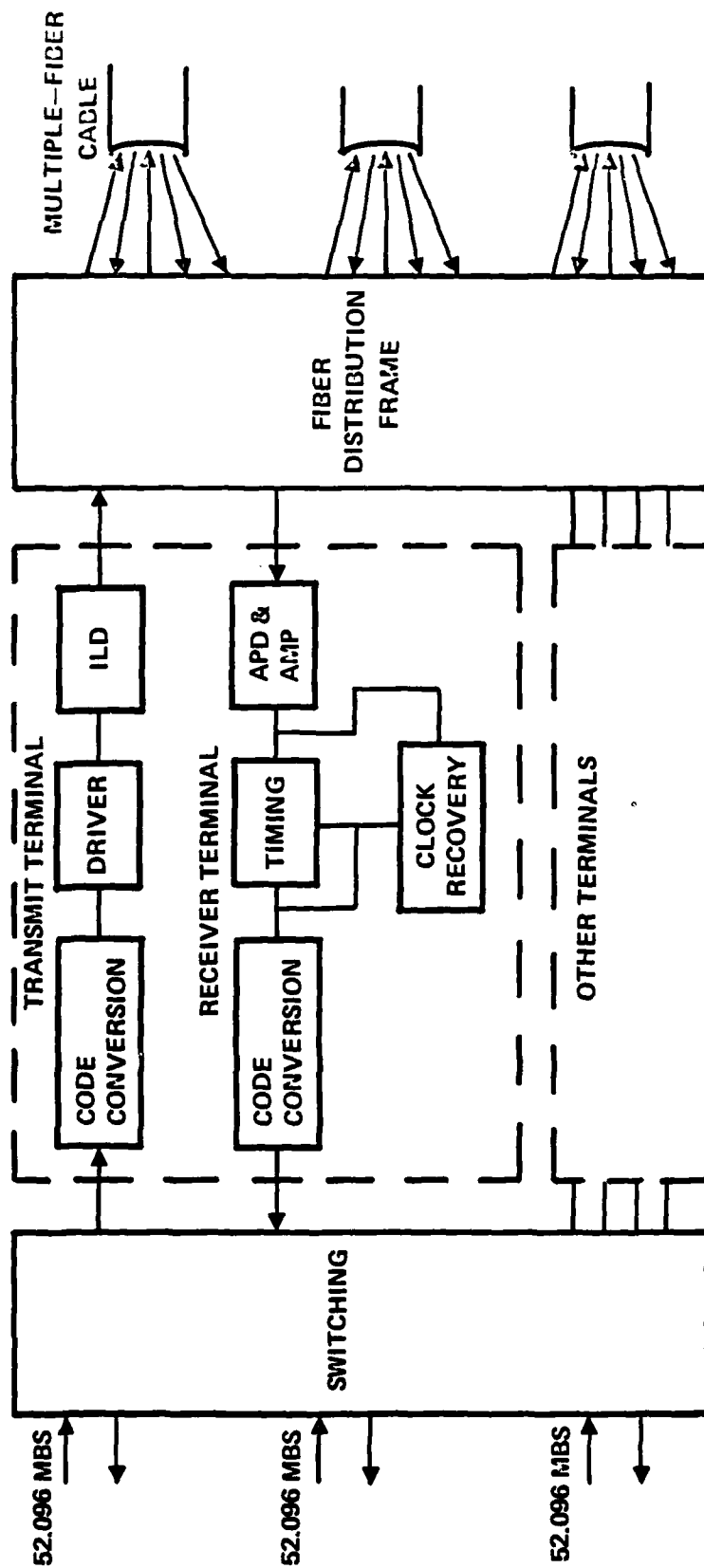
Figure 4-11. Block Diagram of a Fiber Optic Terminal

TABLE 4-3. SPECIFICATION OF AN OPTICAL FIBER SYSTEM

Interface Specifications	
Data Rate	52.096 Mbps $\pm$ 20 ppm
Line Code	Bipolar, B3ZS
Line Impedance	75 ohms $\pm$ 5% unbalanced
Power Level	-1.8 to + 5.7 dBm
Optical Interface	
Transmit Power Output	0 dBm
Receiver Input for 10^{-9} BER	-45 dBm
Fiber Type	Single mode-step index
Optical Source Specifications	
Duty Cycle	100%
Peak Emission Wavelength	1.3 μm
Spectral Linewidth (1/2 peak)	1 nm
Rise Time	.7 ns
Output Power	10 mW
Modulation Rate	1 Gbps
Mode Pattern	Single Mode
Quantum Efficiency	60%
Beam Divergence	45° Vertical
	9° Horizontal
Optical Detector Specifications	
Spectral Response	300 GHz
Peak Response	1.3 μm
Responsitivity	60 A/W

TABLE 4-3. SPECIFICATION OF AN OPTICAL FIBER SYSTEM (CONTINUED)

Fiber Specifications Optical

Region of Zero Dispersion	1.3 μm
Maximum Attenuation	.5 dB/km at 1.3 μm
Bandwidth Fiber Length Product	20 Gbps-km
Nominal Numerical Aperture	.2
Splice Loss	0.5 dB
Connector Loss	0.5 dB

Mechanical

	GENERAL PURPOSE	HEAVY DUTY UNSHEATHED	HEAVY DUTY SHEATHED
Jacketed Fiber Diameter	0.5 mm	1.0 mm	1.0 mm
Cable Diameter	6.1 mm	7.0 mm	9.7 mm
Weight	30 kg/km	39 kg/km	58 kg/km
Minimum Bend Radius	4 cm	5 cm	10 cm
Short-Term Tensile Strength	150 kgf	150 kgf	150 kgf
Number of Fibers	1 to 12	1 to 12	1 to 12

Power Requirements

Switch	250 watts, 48 Vdc.
Fiber Optic Terminal	75 watts, 48 Vdc.

Environmental Specifications

Temperature	0° C to 50°
Humidity	95°
Altitude	500 meters

5.0 LINK DESIGN METHODOLOGY

This section provides link design methodology for the media considered in this study: microwave LOS system, millimeter LOS system and optical fiber system. Emphasis is placed on the link design and budget computation. Details related to system components and propagation characteristics have been documented in the Phase IA and Phase IB reports. These details will not be repeated here. Some changes in system parameters and link budget are expected during the Task II period when link performance and network performance are evaluated.

5.1 MICROWAVE LOS SYSTEM

The terrestrial microwave line-of-sight transmission medium is described in the Phase IA, Appendix A report. This section describes link design and route and site selection.

5.1.1 Route and Site Selection

The following factors are considered in selecting the path and locations of repeaters of links of the proposed system:

1. Site locations are obtained from DCS existing facility location maps and reports (Ref. 5-1 and 5-2).

2. Sites of radio stations are in line-of-sight.

3. Sites should be on U. S. Government-owned land where possible.

4. Sites should be accessible by roadways where possible.

5. Radio paths will not intercept airfields if possible.

6. Radio path lengths will not exceed 80 km for microwave links.

7. Avoidance of RF channels over flat conductive surfaces such as water.

8. An easy access to power distribution and telephone facilities is desirable.

9. Repeater locations at the peak of the mountain are preferred.

Site locations are determined by the above preliminary procedures which are sufficient for the present study.

5.1.2 Maps

For Hawaii, the basic maps (Ref. 5-3) utilized for planning are
published by the U. S. Geological Survey, Denver, Colorado/Washington, D.C.
The scales of the maps covering Oahu Island are 1:24,000 and 1:625,000.
The former provide an excellent source for path profile purposes.

For Germany, the maps (Ref. 5-4) utilized are published by a Germany
agency called "Landesvermessungsamt Rheinland-Pfalz" located at 54 Koblenz,
Postfach 1428. The scale of the maps is 1:50,000. Topographical controur
gradients are nominally 10 meters. Contours of 5 or 2.5 m are provided for.
very steep areas. Roads, highways, radio towers, airports, peak elevations,
rivers, cities, etc. are clearly indicated. The maps provide sufficient
information for path profile purposes.

5.1.3 Earth Curvature

Relative curvature of the earth is an important factor when plotting a
profile chart. Although the surface of the earth is curved, microwave
energy beams tend to travel in a straight line. The beam is normally bent
downward a slight amount by atmospheric refraction, the amount of bending
varying with atmospheric conditions. The degree and direction of bending
can be conveniently defined by an equivalent earth radius factor, K. This
factor, K, multiplied by the actual earth radius, R, is the effective earth
radius. Mathematically, K is expressed by

$$K = \frac{\text{effective earth radius}}{\text{actual earth radius}} \qquad (5-1)$$

The International Radio Consultative Committee (CCIR) collects world-
wide statistical information on the refractivity distribution in the lower
atmosphere to obtain the exact K factor (Ref. 5-5). The relationship
between the earth radius factor K and the mean refractivity gradient
is approximately:

$$K = \frac{1}{1 + 6.37 \times 10^{-3} \times \Delta N} \qquad (5-2)$$

ΔN varies with location and weather. Detailed discussion and sources of
data are documented in Reference 5-6. However, for the present purpose,
Table 5-1 from Reference 5-7 may be used as a guide for selecting
appropriate value of K which is for 99.9-99.99% path reliability. In
Hawaii, a difficult propagation condition is expected due to a coastal

ground fog environment. The K factor falling between 0.5 and 0.66
K = 0.5 will be adapted for the worst case calculation. In Germany, an
average propagation condition of a flat temperate environment corresponding
to a K between 0.66 and 1.0 is considered. K = 0.66 will be adapted for
the worst case calculation.

TABLE 5-1. K FACTOR GUIDE

Propagation Conditions

	Perfect	Ideal	Average	Difficult	Bad
Weather	Standard atmosphere	No surface layers or fog	Substandard, light fog	Surface layers, ground fog	Fog moisture over water
Typical	Temperate zone, no fog, no ducting, good atmospheric mix day and night	Dry, mountainous, no fog	Flat, temperate, some fog	Coastal	Coastal, water, tropical
K factor	1.33	1–1.33	0.66–1.0	0.66–0.5	0.5–0.4

The earth's bulge including atmoshperic refraction is given by
(Ref. 5-7):

$$h = \frac{d_1 \, d_2}{12.74 \, K}$$
(5-3)

where h = earth's bulge in meters

d_1 = distance from transmitter to path obstacle in kilometers

d_2 = distance from path obstacle to receiver in kilometers.

This earth's bulge is needed to examine path profile clearance at
obstacle points along a path plotted on a rectangular grid (see Section
5.1.7 Path Profiling and Appendix).

5.1.4 Fresnel Zones

Fresnel zones are applied to analyze free-space propagation effects,
particularly the effects of terrain and obstructions. A Fresnel ellipsoid
is defined as the geometric loci of all points for which the sum of the

5-3

distances between two antennas is greater by half a wavelength than the direct distance between the antennas. The circular cross section through the Fresnel ellipsoid orthogonal to the direction of propagation is the first Fresnel zone. The radius of the first Fresnel zone is given by Ref. 5-7)

$$r_f = 17.3 \sqrt{\frac{d_1 d_2}{fd}} \qquad (5-4)$$

where f   =   radio frequency in GHz

d   = $d_1 + d_2$ = total path length in kilometers

r_f =   radius of the first Fresnel zone at distance d_1, d_2 in kilometers from the terminals of the path.

Note the radius of the first Fresnel zone is inversely proportional to the square root of the radio frequency. In order to ensure free space propagation, it is essential that there is no obstruction within at least 0.6 RF along the beam centerline of a path.

5.1.5 Tower Height

Adequate tower heights for a link may be determined by plotting the beam path for the proper value of K and superimposing this path on the terrain profile such that 0.6 first Fresnel zone clearance is achieved over the terrain object causing the greatest blockage. Generally, if the obstacle is near mid-path, the tower heights are made equal at each end of the path. If the obstacle is not in the center, a small elevation change at the site nearer the obstacle will have the same effect as a larger elevation change at the other end. Therefore, an elevation change at the site nearer the obstacle is preferred.

The tower height required for clearance over a smooth earth increases as the square of the path lengthens. Figure 5-1 (Ref. 5-8) shows the relationship for tower height versus path length K = 0.66 and 0.6 first Fresnel zone clearance. As can be seen from Figure 5-1, a 35 m tower height is required for a 30 km path while 56 m height is required for a 40 km path.

5.1.6 Scales of Path Profile

Different types of horizontal and vertical scales are utilized in
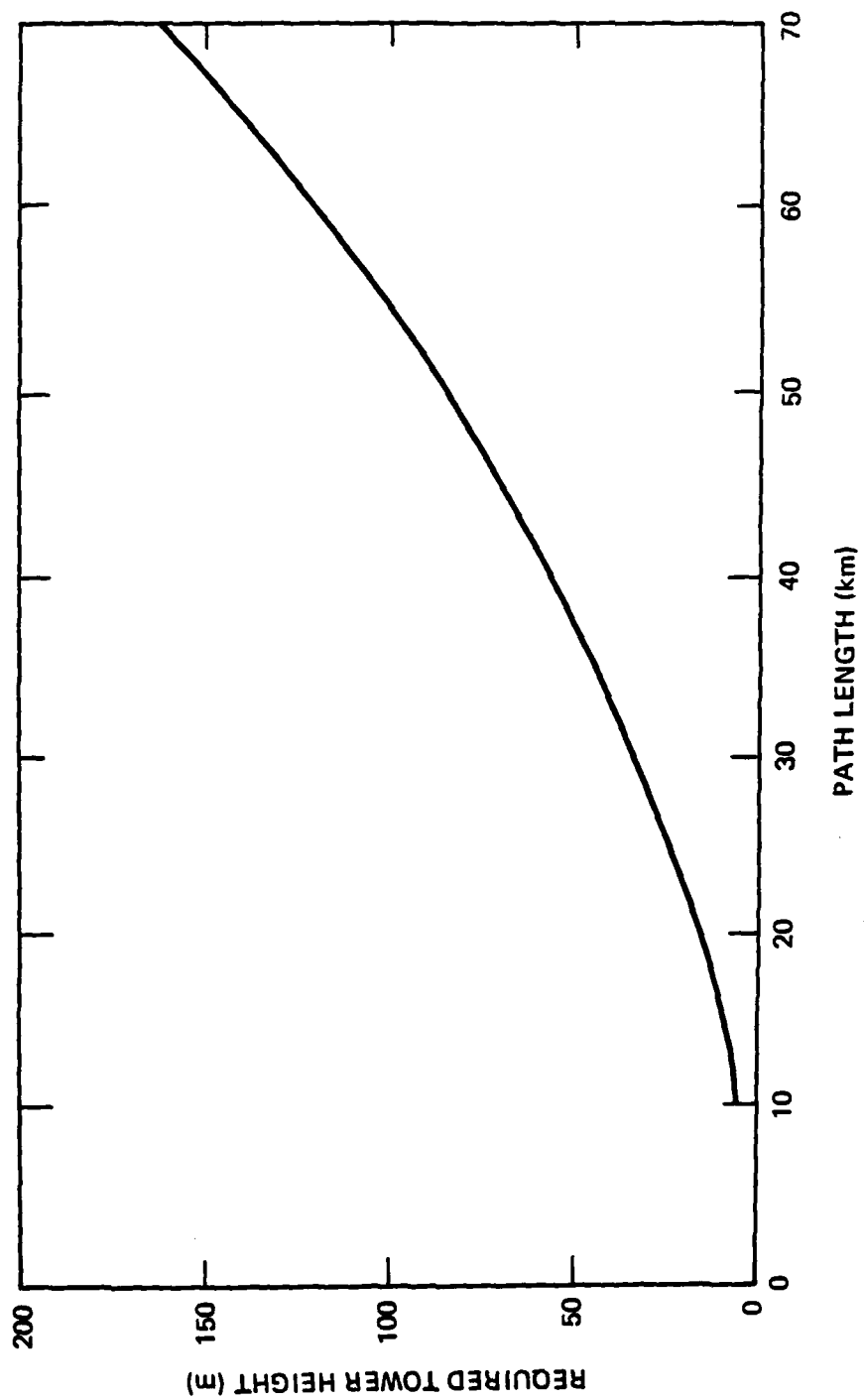
Figure 5-1 Tower Height Required For Smooth Earth Clearance For k = 2/3, 0.6 First Fresnel Zone Clearance and Equal Antenna Heights

producing the path profile charts as summarized in Table 5-2. Various
path profile charts were prepared for link path study. All plotted path
profiles are given in the Appendix.

TABLE 5-2. SCALES UTILIZED IN PATH PROFILE CHARTS

Elevation (m)	Vertical Scale (m/div)	Path Length (km)	Horizontal Scale (km/div)
500	50	10	0.5
1000	100	10	0.5
500	50	20	1.0
1000	100	20	1.0
1000	100	40	2.0
1000	100	50	2.5
1000	100	80	5.0

Five different horizontal scales have been chosen permitting path
lengths ranging from 10 km to 80 km. Two different vertical scales are
sufficient for all terrains. A basic elevation scale of 50 meter/division
has been found to be quite convenient for most of the cases. For paths in
hilly or mountainous terrain, a compressed scale of 100 meter/division is
more convenient.

5.1.7 Path Profiling

Path profiles are drawn following the steps below:

1. Select proper map(s) which cover the area of interest.

2. Select tentative sites for radio stations using the criteria
   specified inpa ragraph 5.1.1.

3. Draw a straight line on the map(s) connecting the two radio
   stations.

4. Choose repeater stations if necessary, using the criteria
   specified in paragraph 5.1.1.

5. Select the scales for the path profile chart in Table 5-2.

6. Show terrain variation between the two radio stations, indicating obstacles, rivers, etc. If the obstacles are too high and will block the line-of-sight clearance, go back to Step 4.

7. Determine K factor from Table 5-1.

8. For each obstacle point, compute earth bulge using equation 5.1-3.

9. Compute Fresnel zone clearance using equation 5.1-4 and use 60% of the first Fresnel zone ($0.6 \, r_f$).

10. Plot the height above sea level of each obstacle point on the graph paper. Add earth bulge from equation 5.1-3 and 60% of the first Fresnel zone clearance. For existing tree growth, add 15 m. For smaller vegetation, add 3 m.

11. Determine the antenna tower heights to insure line-of-sight clearance above the points plotted in Step 10. Then draw a line between the two towers and indicate the heights on the path profile chart. If extremely high tower heights are indicated, above 50 m, go back to Step 4 choosing a new repeater station and repeat the steps thereafter to attempt to find a lower tower height.

Geographical coordinates of the stations terminating each path are computed from the maps to the nearest second of latitude and longitude. The distance in kilometers between the end stations is measured to the nearest tenth of a kilometer. The elevation of stations in meters is found from the maps. The geographical coordinates, the distance and elevations are indicated in the path profile charts. The path profile charts prepared for Hawaii and Germany are found in the Appendix.

5.1 8 Diversity Operation

Diversity reception can be employed in cases of very adverse propagation conditions or long links. Under these circumstances, two received signals or more with the same information content are usually formed by the following two methods:

Space Diversity (reception over two propagation paths). A single transmitted signal is received by two spaced antennas. A common practice

of microwave LOS system is employing two antennas mounted at different heights on a tower, usually referred to as height diversity. A space diversity system with hot standby transmitter is shown in Figure 4-1.

Frequency diversity (reception of two radio frequencies). Two signals with the same information content, but at different frequencies, are received by one or two antennas. A frequency diversity system is shown in Figure 4-3.

Quadruple diversity. In a hybrid quadruple system, the transmission is on two frequencies and the reception of these two frequencies is done with two spaced antennas, thus providing a combination of space diversity and frequency diversity.

Diversity operation reduces the effect of fading and thus reduces the time during which the signal level is below the minimum acceptable level. The diversity improvement factor is defined by (Ref. 5-9):

$$I = \frac{U_{ndp}}{U_{div}} \tag{5-5}$$

where I is the diversity improvement factor, U_{div} is the probability of fading outage with diversity, and U_{ndp} is the non-diversity fading outage probability.

The non-diversity fading outage probability for a given path and fade margin (F) can be computed by (Ref. 5-9);

$$U_{ndp} = a \times b \times 10^{-5} \times f \times D^3 \times 10^{-F/10} \tag{5-6}$$

Where f = frequency in GHz

D = path length in km

F = fade margin in dB

The constant "a" assumes the value of 4, 1, and 1/4 for very smooth terrain, average terrain with some roughness, and very rough mountainous terrain respectively. The constant "b" takes the value of 1/2, 1/4, and 1/3 for gulf coast or similar hot, humid areas, for northern or normal interior temperate regions, and very dry mountainous terrain respectively.

According to measurements by W. T. Barnett (Ref. 5-10) and A. Vigants (Ref. 5-11), the diversity improvement factor on typical line-of-sight paths is given approximately by

$$I_{SD} = \frac{10^{-3} \times S^2 \times f \times 10^{F/10}}{D} \qquad (5-7)$$

for space diversity and by

$$I_{FD} \ (7 \sim 8GHz) = \frac{1}{8} \frac{(\Delta f)}{f} \times 10^{F/10}$$

for frequency diversity,

where f = frequency in GHz

$\quad$ S = vertical antenna spacing for space diversity in meters

$\quad$ f = frequency separation for frequency diversity in GHz

$\quad \Delta$F = fade margin in dB

$\quad$ D = path length in km.

Experience indicates that the improvement in hybrid diversity systems is mainly due to the space diversity effect (Ref. 5-9). Consequently, it is assumed that

$$I_{hybrid} = I_{SD} \qquad (5-8)$$

and the quadruple improvement factor is calculated as if the path were straight space diversity. Hence, the quadruple diversity is not recommended for the system design.

Fade margin is the dB difference between the minimum acceptable RF input level and the normal signal level. Most line-of-sight microwave systems are engineered with fade margins in the range of 30 to 40 dB.

Space diversity allows essentially full freedom of choice as to antenna spacing, subject to economic and physical limitations. The method of choosing a spacing depends primarily on whether the significant multipath fading on the particular path is likely or not. Experience has indicated that excellent diversity will be obtained with minimum vertical spacing intervals of about 20 meters at 2 GHz, 15 meters at

.1 GHz, 10 meters at 6 GHz, and 4 meters to 6 meters at 12 GHz. Larger spacing can be expected to provide even better diversity improvement factors, but may impose undesirable problems in tower heights, clearance, etc.

Most of the existing hybrid systems were not really designed in this manner (Ref. 5-12); they were originally built as frequency diversity systems and later modified to include the spaced antennas because of poor performance. It has, of course, the same disadvantage as ordinary frequency diversity, in that it requires two RF frequencies to obtain one working channel. To illustrate the method, consider a 20 km path with average terrain, with some roughness, in a normal interior temperate climate, operating at a frequency of 8 GHz with a fade margin of 30 dB. Improvement factors will be computed for this path without diversity, with 5% frequency diversity, and with 10 meters vertical space diversity.

Non-Diversity Case

Equation (5-6), with the proper values for the various factors substituted, gives

$$U_{ndp} = 1 \times (\tfrac{1}{4}) \times (10^{-5}) \times (8) \times (20)^3 \times 10^{-3} = 1.6 \times 10^{-4}$$

This is the probability of fading outage without diversity. The reliability for non-diversity is 0.999974.

Space Diversity

From Equation (5-7),

$$I_{sd} = \frac{10\text{-}3 \times (10)^2 \times 8 \times 10^3}{20} = 40$$

and substituting into Equation (5-5),

$$U_{sd} = \frac{U_{ndp}}{I_{sd}} = \frac{1.6 \times 10^{-4}}{40} = 4.0 \times 10^{-6}$$

Therefore, the reliability for space diversity is 0.999996.

Frequency Diversity

Using Equation (5-8),

$$I_{FD} = \frac{1}{8} \left(\frac{5}{100}\right) \times 10^3 = 6.25$$

and substituting into Equation (5-5)

$$U_{sd} = \frac{1.6 \times 10^{-4}}{6.25} = 2.56 \times 10^{-5}$$

Hence the reliability for frequency diversity is 0.9999744.

From the above example, it is seen that the improvement factor of space diversity is larger than that of frequency diversity.

5.1.9 Combiners

There are several combining methods to process diversity signals with the same information content. One simple switch combiner selects the better of the two input signals. However, there are adder combiners, ratio combiners, and others which more efficiently use the two signals and can improve performance substantially if adjusted correctly.

Combiners can also be classified in accordance with the point in the system where combining takes place. Post detection combining combines only after both signals have passed through complete receivers, have been detected, and brought down to base band. This is widely used as a simple and very reliable method. The other method is called predetection combining which combines signals at the IF output or at RF in the waveguides ahead of the receiver. In principle, the earlier the signals are combined, the better is the ultimate performance. The principal difficulty of predetection combiners is to adjust the phases of the individual signals so that signals always add. In recent years, predetection combiners have been much improved. Except for frequency diversity signals which cannot be combined at RF, the combining technique is independent of the type of diversity used.

5.1.10 Propagation Reliability and Diversity Considerations

It was indicated in the "Diversity Operation" section that diversity technique, when properly applied, can reduce the effects of multipath fading on line-of-sight systems to insignificance. Whether or not the

considerable expense of providing diversity is justified will depend very critically on the nature of the communication paths and the degree of outage which is acceptable.

In Section 3.3.2.1 microwave LOS link availability, unavailability of a single 48 km LOS is allocated to be 0.00004, where 0.000007 due to propagation outage and 0.000033 due to equipment failure. The value of 0.000007 (or 0.999993 reliability) is a very high reliability requirement. Employing diversity technique is almost mandatory for long distance paths and adverse propagation conditions.

Table 5-3 provides a simple means of translating a given system reliability percentage into outage time per year which is more easily related to experience. For example, 0.99999 value would correspond to about 5.3 minutes of outage time per year, while 0.999999 value would correspond to only about 32 seconds per year. The latter value is typical of per path objectives, for the highest reliability systems.

TABLE 5-3. RELATIONSHIP BETWEEN SYSTEM RELIABILITY AND OUTAGE TIME

Reliability	Outage	Outage Time Per Year
0.99	0.01	88 Hours
0.999	0.001	8.8 Hours
0.9999	0.0001	53 Minutes
0.99999	0.00001	5.3 Minutes
0.999999	0.000001	32 Seconds

5.1.11 Link Budget Analysis

A preliminary link budget analysis is shown in Table 5-4. It provides a numerical values for some major system parameters. In Task 2, reevaluation of alternatives will be conducted, some of the parameters, particularly fade margin and time availability will be reevaluated and amended as necessary.

The system margin for a typical 20 km link is approximately 20 dB. Considering a long link of 50 km with the same system parameters as Table 5-4, the system margin will be reduced to 4 dB due to additional

TABLE 5-4. MICROWAVE LOS LINK ANALYSIS PATH LENGTH 20 kM @ 5 x 10^{-5} UNAVAILABILITY

PARAMETER	VALUE
Frequency	8 GHz
Path Length	20 km
Bandwidth	13 MHz
Data Rate (Bandwidth Efficiency 4 bit/sec/Hz)	52 Mbps
RF Transmitter Power (2W)	3 dBW
Losses Associated with Transmitter Station	3 dB
Transmitter Antenna Gain (2 m diameter)	42 dB
Space Loss	. 137 dB
Loss due to all other transmission loss (scintillation, reflection, etc.	3 dB
Fade Margin	30 dB
Receiver Antenna Gain (2 m diameter)	42 dB
Losses Associated with Receiver Station	3 dB
Receiver Noise Figure	5 dB
Receiver Noise	-133 dBW
SNR @ 10^{-6} BER (16 Level QAM)	21 dB
System Margin	20 dB

space loss of 8 dB and fade margin of 8 dB. For extremely long path
length links, one or more of the following actions are chosen to compensate
additional space loss and fade margin:

- Increase antenna size

- Increase transmitter power

- Separate space diversity antennas (max. 15 meters)

- Use low noise receiver.

5.2 Millimeter Wave LOS System

The millimeter wave LOS transmission media description in the IA
and IB reports will not be repeated here.

There are many similarities between a millimeter wave LOS system
and a microwave LOS system. For route and site selection, the methodology
developed in Section 5.1.1 to Section 5.1.7 is also applicable to the
millimeter LOS system. A few exceptions are as follows:

- Radio path length will not exceed 10 km.

- Radio frequency is 35 GHz.

- The radius of the first Fresnel zone will be small, due to
  shorter path length and higher radio frequency.

The path profile charts prepared for Hawaii and Germany are in the Appendix.

For the link design the methodology developed in Section 5.1.8 is
applicable. However, there are some fading losses (2), (3) which, while
negligible in the microwave link design, are major millimeter wave
considerations. Such losses are rain attenuation, attenuation by
atmospheric gases and scintillation fading. In section 5.2.1, 5.2.2
and 5.2.3, each of these parameters will be addressed separately.

5.2.1 Rain Attenuation

Rain attenuation results in transmitted power loss both by absorption and by scattering. The amount of attenuation is directly related to the rainfall rate, radio frequency, and the distribution of rain along the path. Accordingly, in areas of heavy rainfall where highly reliable communication is required, short path lengths are recommended.

Rain attenuation has been investigated intensively. Recent studies deal with the following areas of interest; (1) rain modeling on a globe basis, (Ref. 5-13 to 5-18), (2) rain attenuation effects on radio wave propagation (Ref. 5-19 to 5-23), (3) impacts of rain attenuation on terrestrial and satellite communications systems (Ref. 5-24 to 5-31). Presently, there are some problems for predicating communications systems performance in a rain environment because of the following reasons:

1. Surface point rain rate averaged over time intervals, such as tens of minutes, hours, and days cannot easily relate to the rain rate along a path a few kilometers long. The only available experiment to relate space point average rain rate to path average rain rate is for a path only three kilometers long.

2. Detailed rain cell structure both spatial and temporal are not available.

3. Rain statistics from weather reports are usually averaged over days, months, or years which are not suitable for our present purpose due to the high availability (0.9999 and above) required.

However, the currently available rain models, various attenuation computation and link availability predication methodologies provide comparable results.
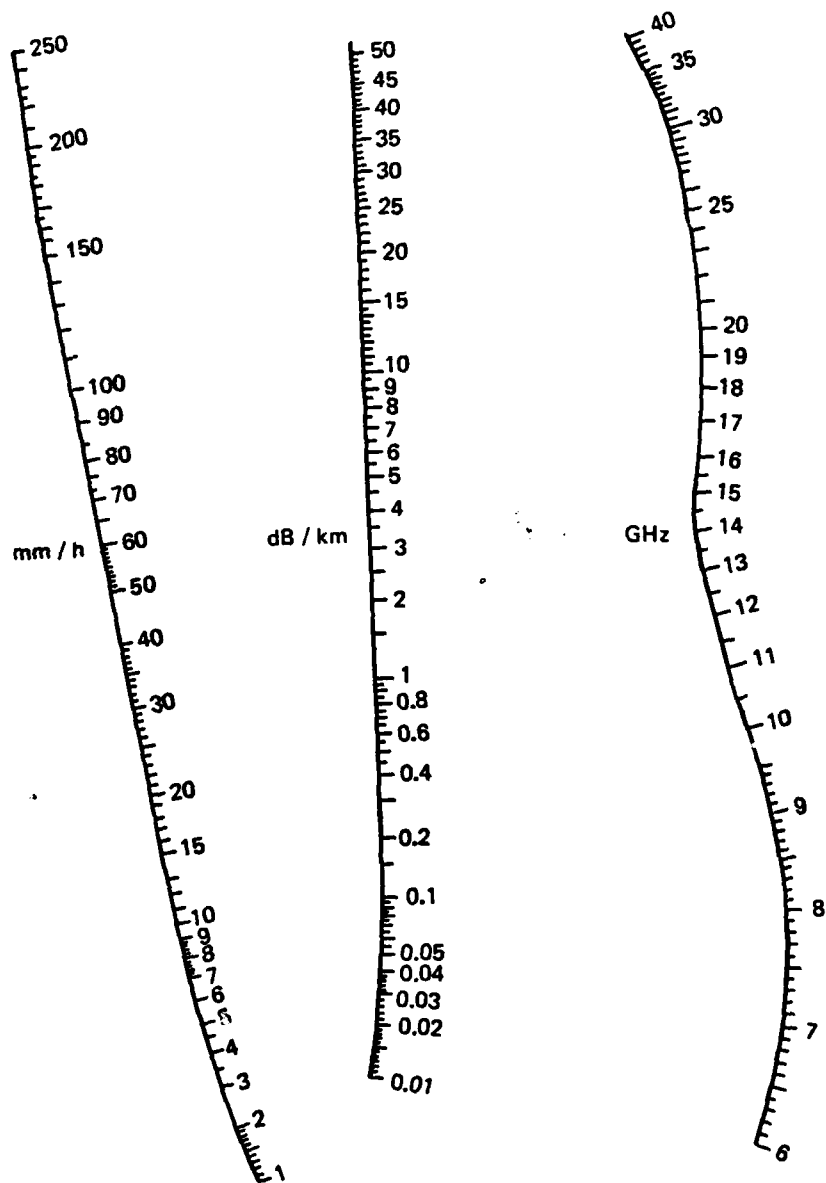
Figure 5-2   Rain Attenuation Coefficient Nomograph
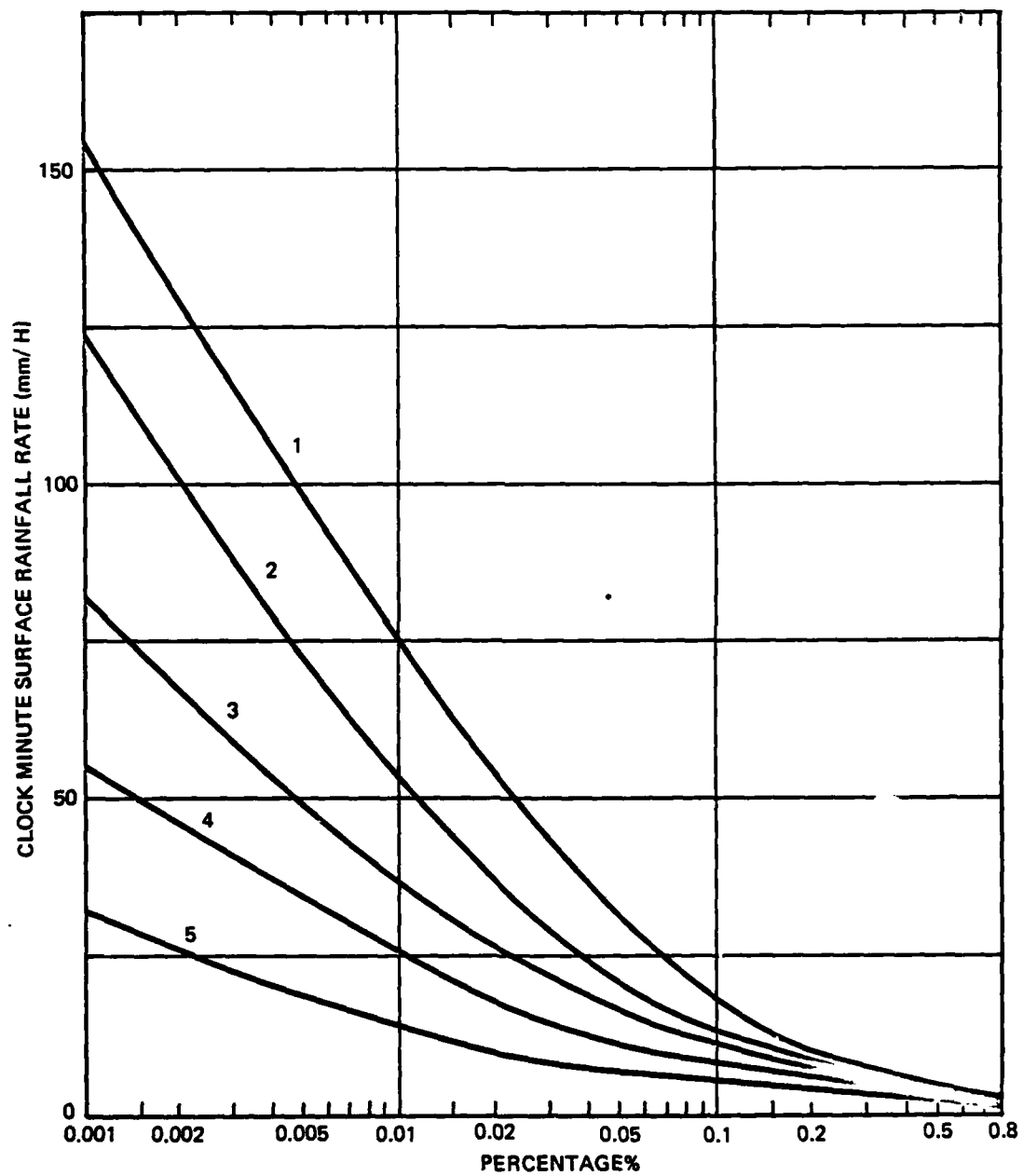
Figure 5-3 Percent Of Average Year Rainfall
Rate Is Exceeded For Rain Climates

For the present system design, the following approach is adopted.

Attenuation due to rainfall from 6 GHz to 40 GHz and for rainfall rates of 1 mm to 250 mm per hour can be found by using nomograph as shown in Figure 5-2.

For example, on a 36 GHz path undergoing a uniform rainfall at a rate of 50 mm/hr, the excess attenuation due to rain is 12.6 dB/km. Under these conditions, it is obviously impossible to maintain transmission over long path length. However, the temporal and spatial distributions of such severe rain storms are highly restricted (Ref. 5-25), therefore, parallel paths a few km apart, or a millimeter wave and microwave mixture may provide an effective improvement.

Five rain-climate zones are proposed by CCIR (Ref. 5-16). Zone 1 may be used to characterize the rain climate for Hawaii; zone 3 may be used for West Germany. From this, an estimate of cumulative distribution, identifying the percent of an average year for which the rainfall rate is exceeded for these zones may be found using Figure 5-3.

The rain zone is not intended to provide the details required for design of systems in a particular locality; rather, it should be used as a rough indicator of the general areas in which rain attenuation may be a significant design consideration. The value of percentage of average yearly rainfall rate exceeded in rainy climates corresponds to the reliability of the link considered.

A rough estimate of the time distribution of rain attenuation for a given path may be obtained by the following steps:

1. Select proper values for the percent of average yearly rainfall and the rain zone of interest.

2. Find the corresponding rainfall rate in mm/hr in Figure 5-4.

3. From Figure 5-2, find the rain attenuation in dB/km given the radio frequency in GHz and the rainfall rate in mm/hr.

4. Multiply the rain attenuation in dB/km found in Step 3 by the path length.

For example, in Hawaii, a 3.5 km radio link operating at 36 GHz and slightly more than a 0.005₃ rainfall exceeded rate experiences a rainfall rate of 70 mm/hr and a rain attenuation of 17 dB/km found from Figure 5-3 and 5-2, respectively. The total rain attenuation of the link is 68 dB.

5.2.2 Attenuation by Atmospheric Gases (Oxygen and Water Vapor)

Atmospheric absorption due to oxygen and water vapor is negligible at frequencies below 10 GHz. However, above 10 GHz, the effect is quite large and dependent on the operating frequency. Figure 5-4 shows the attenuation coefficient for atmospheric gases (dB/km) vs. frequency (GHz). The attenuation coefficient is around 0.06 dB/km in the 30 to 40 GHz range.

5.2.3 Other Parameters

Other factors affecting millimeter wave propagation are scintillation fading, attenuation due to snow, cloud, and fog, reflection due to ice, etc., except in the case of scintillation fading, effects of these factors are small compared to rainfall effect.

Scintillation or rapid fading is caused by multipath interference between waves travelling over slightly different paths. Different paths are created by globules of inhomogeneity in the refractive index of the atmosphere which break up a wave and defract or refract components into slightly different directions. Globules of inhomogeneity are caused by turbulence which is a time varying random process causing continual change in the relative phase of different waves that contribute to the field arriving at a given point where scintillation is observed. Resulting constructive and destructive interference can produce large random amplitude modulation of the received signal.

5.2.4 Diversity Methods

The operating reliability of millimeter-wave links can be improved by utilizing diversity methods (as is customary in standard microwave link practice). In practice, one has the following methods of diversity (Ref. 5-32) operations: (1) power-level; (2) frequency diversity; and (3) network switching diversity.

Power-level diversity is a straignt forward and attractive approach to the problem if the capability of automatic power-level switching between
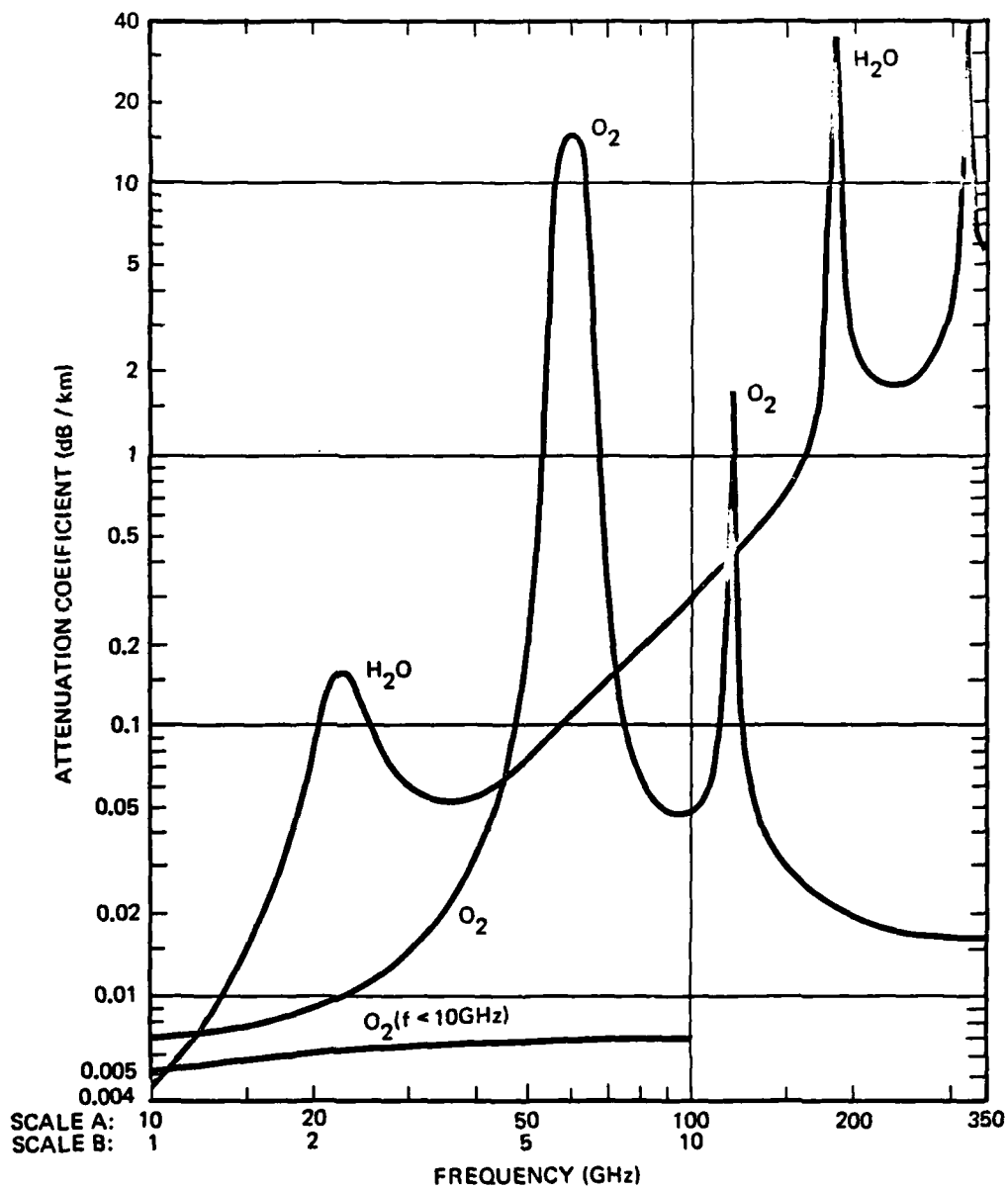
Figure 5-4   Specific Attenuation Coefficient for Atmospheric Gases
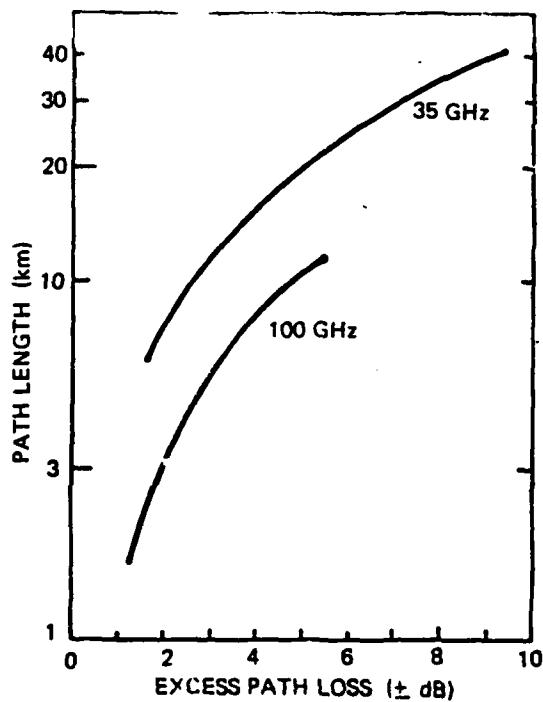
Figure 5-5. Scintillation Fading for 35 and 100 GHz.

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| | 1.0 | ‖ 2.8 | ‖ 2.5 |

‖ 1.0   ‖ 2.8   ‖ 2.5
          ‖ 3.2   ‖ 2.2
          ‖ 3.6
          ‖ 4.0   ‖ 2.0

‖ 1.1   ‖ 1.8

‖ 1.25   ‖ 1.4   ‖ 1.6
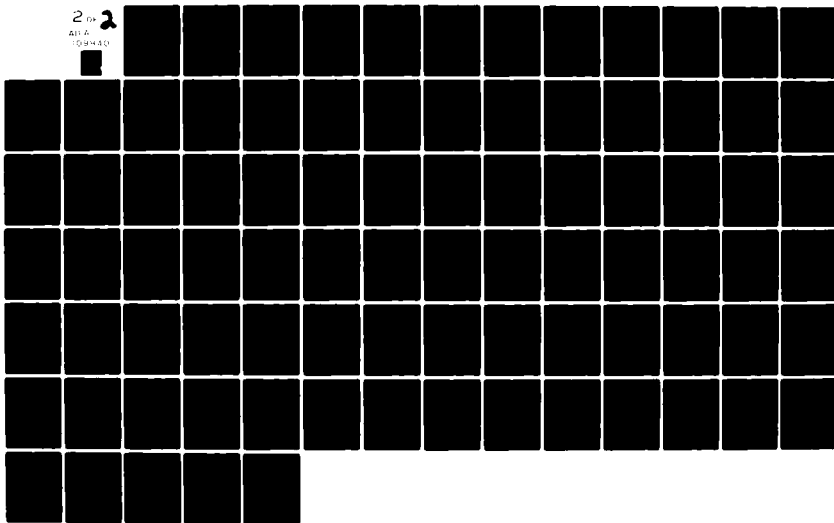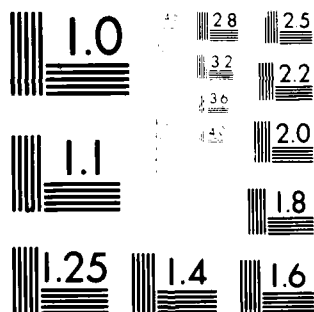
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS

low-level and high-level output or continuous power level adjustment is equipped. The objective would be to take advantage of very low transmitter power requirements prevailing most of the time, but to provide enough power for maintaining transmission during the short periods of high intensity rainfall. In many cases, low power in the order of a few milliwatts could be used for 99.9 percent of the operating time. It would only need to be switched to higher power to offset heavy rainfall attenuation during 0.1 percent of the time and maintain the required reliability.

As an example of frequency diversity, consider a link with a hop distance of 4 km and normally operating at frequency 36 GHz. Inspection of Figure 5-2 reveals that during heavy rainfall, switching from 36 GHz to lower frequency would substantially reduce the rain attenuation.

Network switching diversity is based on the availability of meshed networks of communication facilities, and might be called geographical diversity or routing diversity. In case of heavy rainfall in a limited area of the meshed network, traffic is routed to go around the affected area.

The typical value of route separation between two routes varies from two to ten kilometers (Ref. 5-32). Properly applying diversity methods, a communication system can be well protected against the large values of attenuation caused by heavy rainfall. Hence, increasing path length and/or reduction transmitter power are possible and still maintain the same reliability requirements as non-diversity systems.

5.2.5 Link Budget Analysis

A preliminary link budget analysis is shown in Table 5-5. In Task 2, reevaluation of alternatives will be conducted, some of the parameters will be reevaluated and amended as necessary.

The parameters shown in Table 5-5 are selected from Table 4-2 millimeter wave radio equipment specifications. For millimeter wave path, heavy rain showers tend to mix the lower atmosphere and eliminate multipath fading, so the entire rain attenuation margin is available to combat fade margin. Therefore, only rain attenuation is considered in the link analysis. The system margin for a 3.5 km link at rainfall

TABLE 5-5. MILLIMETER WAVE LOS LINK ANALYSIS
PATH LENGTH 3.5 kM WITH 5×10^{-5} UNAVAILABILITY

PARAMETER	VALUE
Frequency	36 GHz
Path Length	3.5 km
Bandwidth	17.3 MHz
Data Rate (Bandwidth Efficiency 3 bps/Hz	52 Mbps
RF Transmitter Power (2W)	3 dB
Transmitter Antenna Gain (1m diameter)	49 dB
Losses Associated with Transmitter	1.0 dB
Space Loss	+135.7 dB
Loss due to Rain Attenuation	68 dB
Loss due to All Other Transmission Loss (Scintillation, reflection, oxygen and water vapor)	3.0 dB
Receiver Antenna Gain (1 m diameter)	49 dB
Losses Associated with Receiver	1.0 dB
Receiver Noise Figure	5 dB
Receiver Noise Power	-131.5 dBW
SNR @ 10^{-6} BER (8-PSK)	15.7 dB
System Margin	3.1 dB

zone 2 (Hawaii) is approximately 3.1 dB as shown in Table 5-5. For the same system specifications at rainfall zone 3 (Germany) the system margins are approximately 19.1 dB for 4 km link, 5.2 dB for 5 km link.

5.3 Fiber Optic System

Currently, suitable optical fiber communications technology exists to satisfy the requirements for both Hawaii and Germany. Optical fiber links of five or more kilometers operating up to DS-3 (47 Mbps) are commonplace. Major telecommunications suppliers, such as Western Electric, GTE-Lenkurt and NEC, have announced production equipment for DS-3 transmission between central office exchanges with repeater spacing varying from 5 to 10 kilometers depending on required bandwidth and other factors.

Fiber losses and material dispersion are lowest when operated at wavelengths in the vicinity of 1.3 microns. Currently, almost all the research and development work related to fiber optic components or systems is performed in this range of frequency. At those wavelengths, repeaterless transmission has already been demonstrated at 45 Mbps over a span of 55 km. Such performance, optimum for fulfilling the needs of Hawaii and Germany, will be standard by the year 2000, with even better performance predicated.

Detailed descriptions of fiber optic components and systems are addressed in the Appendix A of Phase IA report, thus this section will only discuss a long-haul, large-capacity fiber optic communication system design methodology.

5.3.1 Optical Fiber Communication Systems Overview

The optical fiber communication system consists of three major components that differ from other conventional communication systems:

1. Optical source;   Light emitting diode (LED) or injection laser diode (ILD)

2. Optical Fiber;   Single mode or multimode fiber, step-index or graded-index fiber

3. Photodetector;   Avalanche photodiode (APD) or PIN diode.

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Some aspects of these components related to system design are discussed in the following sections.

5.3.2 Optical Source

Two optical sources; LED or ILD are currently being used in long-haul communication systems. The ILD is a threshold device which begins to turn on at current of about 100 mA and is fully on at an additional 20 mA or so. It can be switched on and off at up to gigabit rates with careful design of the driver circuitary (Ref. 5-33). The LED is roughly a linear power versus current device. Modulation speeds for the LED are limited to around a few hundred MHz or less.

The ILD can couple a few milliwatts of light into a fiber about 10-50 times more effieiently than a LED. Its optical bandwidth is much less than that of an LED so that dispersion of transmission fiber is not a problem. However, an ILD is more sensitive to gradual degradation and to temperature variance. Table 5-6 shows the repeater spacing for LED light source system using a 0.6 dB/km loss cable. (Ref. 5-34).

TABLE 5-6. EXPECTED REPEATER SPACING FOR
1.3 µm (InGa) LED BASED LIGHTWARE SYSTEM

Data Rate (Mbps)	1.5	6.3	45	274
Spacing (km)	27	23	17	8

By comparison to LED's, ILD's system can have more than 2 GHz modulated bandwidth with a span longer than 50 km without using a repeater because it has greater coupling efficiency to low numerical aperture (NA) (NA <0.2) optical fibers and lower dispersion. The ILD's diode has about 10 mW continuous output and can couple more than 50 percent into 0.2 NA fibers.

Therefore, LED's are adequate for data links and short links, lasers are appropriate for long-haul, large-capacity systems.

5.3.3 Optical Fiber

For large-capacity and long-haul systems where a large bandwidth is required, a single mode fiber operating at longer wavelengths (1.3 µm presently, 1.55 µm in the future) is shown to be superior to a multimode

fiber. As stated in A.9.3.1 in the Phase IA, Appendix A Report, a single mode step-index fiber defined by the normalized frequency V is less than 2.405. Optical attenuation of a silica-based single mode fiber is attributed to the following four losses (Ref. 5-35).

- Intrinsic loss   0. 31 dB/km

- Loss due to imperfections in   0.02 dB/km
  the waveguide

- OH absorption loss   0.1 dB/km

- Loss due to microbends in the   0.04 dB/km
  cabling process

Therefore a conservative fiber cable loss of 0.5 dB/km is predicated for the year 2000 and used for the system design. It is assumed that fusion splicing with 0.3 dB loss each will be used for a single mode step-index fiber and that one splicing will be needed for every two kilometers. The connector loss for the fiber cable is taken to be 0.5 dB each.

Dispersion at wavelength 1.3 μm is near zero. However, for the current design, 2 ps/km/nm is assumed (Ref. 5-36). Another dispersion related measure is bandwidth-distance product which is taken to be 50 GHz km (Ref. 5-37).

5.3.4 Photodetector

There are basically two types of photodiodes: one is the PIN diode, the other is APD. A PIN generates a single electron-hole pair per absorbed photon as given by

$$I = I_p = \frac{nq}{h\nu} p \qquad (5-9)$$

where $h\nu$ is the photon energy, q is the electron charge, P is the optical power incident on the detector, and η is the quantum efficiency of the detector. Whereas an APD exhibits internal gain, generating more than a single electron-hole pair through the process of impact ionization. The current generated by APD is given by

$$I = Mi_p = M \frac{nq}{h\nu} p \qquad (5-10)$$

where M is the avalanche gain.

The total primary current includes contributions from the signal, from any background radiation, and from leakage currents produced by the detector (dark current), i.e.,

$$I = I_p + I_B + I_d \qquad (5\text{-}11)$$

where I_B and I_d are current caused by background radiation and dark current respectively.

For a simple binary communicatiion system where in an interval of time of duration T seconds, a transmitter produces either pulse or no-pulse, the probability of making an error is given by (Ref. 5-33)

$$P_e = \exp\left(-E_R/h\nu\right) \qquad 5\text{-}12)$$

where E_R is the received pulse energy and h is Planck constant, 6.625×10^{-34} Jule-sec. For a 10^{-7} BER, E_R is found to be 16 hν. In other words, 16 photons per received pulses are required to achieve 10^{-7} BER. That number of photons is called "quantum limit". Since the optical communication systems employ a half existing and half non-existing binary modulation scheme, the average received power P_q is 16/8 hνB, where B is the data rate. For given data rate 100 Mbps and 1.3 μm wavelength, the quantum limit of received power is 1.22×10^{-10} Watt or -69 dBm at the receiver for a 10^{-7} BER. Typical practical receivers are 15-25 dB less sensitive than this. This can be accounted for as follows:

- Transmitter imperfections   1-3 dB

- Nonideal detector quantum efficiency   1-3 dB

- Tradeoffs between receiver sensitivity   1-3 dB
  and dynamic range requirements

- Thermal noise of preamplifier   13-15 dB

Therefore, the median value of the minimum required power level is assumed to be -49 dBm.

5.3.5 Link Budget Analysis

With the background discussions presented in previous sections, a preliminary link budget is shown in Table 5-7.

TABLE 5-7. LINK BUDGET ANALYSIS
FOR THE PROPOSED FIBER SYSTEM

PARAMETER	VALUE
Optical Wavelength	1.3 µm
Path Length	50 km
Data Rate	52 Mbps
ILD Output (10 mw)	10 dBm
Power Degradation at End of Life	2 dBm
Coupling Loss (NA = 0.2)	3 dB
Fiber Loss (0.5 dB/km)	25 dB
Splicing Loss (0.3 dB each)	7.5 dB
Connector Loss (0.5 dB each)	4.0 dB
Detector Coupling Loss	0.5 dB
Detector Temperature Degradation Loss	2 dB
Received Power	-32 dBm
Required Received Power (10^{-6} BER)	-49 dBm
System Margin	17 dB

The light pulse width of a 50 Mbps system is 20 ns. After traveling 50 km along a fiber with dispersion of 2 ps/km/nm, the total pulse spread would be 100 ps or 0.1 ns which is only 0.5% of the original pulse width. Here assumption is made that the spectral width of the ILD is 1 nm. Therefore, fiber dispersion would not degrade the system BER performance. This result is also consistent with the bandwidth and distance product of 50 GHz-km since the product of the system is only 2.5 GHz-km.

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6.0 HAWAII ALTERNATIVE SYSTEM DESIGNS

Four transmission alternatives are proposed to satisfy common user and wideband user requirements in Oahu Island, Hawaii as follows:

1. Microwave LOS System

2. Millimeter wave LOS System

3. Fiber optic system

4. Leased Common Carrier System

These alternatives are presented in this section.

6.1 REQUIREMENT AND GENERAL CONSIDERATION

For brevity of notation, three designators for each location are listed in previous Table 6-1 and will be used hereafter. Also, Table 6-1 contains the location of radio sites in alphabetical order. The link connectivity and its channel capacity requirements for the common user and wideband user are tabulated in Tables 6-2 and 6-3 respectively. Figures 6-1 and 6-2 show the Common User and Wideband User connectivity diagrams. Radio sites locations are adapted from DCS III Phase I reports and from topographic maps. The total number of channels required at each node is given in Table 6-4. It is apparent that the heavy traffic nodes are Wahiawa, Pearl Harbor, and Hickam. Alternatives 1, 2, and 3 are to be implemented as government-owned facilities. A leased common carrier system is the fourth alternative.

Various network configurations have been presented in the Phase I Report. Consideration was given to a centralized or star network, double-star network and mesh type network. Based on performance evaluation, reliability, survivability and cost, it was found that a mesh type network is optimum. Therefore, only a mesh type network will be used for the alternative system designs described in this section.

TABLE 6-1. SITE DESIGNATORS AND LOCATIONS FOR OAHU, HAWAII

NO.	SITE LOCATION	LATITUDE	LONGITUDE	DESIGNATOR
1	BARBERS POINT	21° 19' 15"	158° 04' 45"	BBP
2	CAMP SMITH	21 23 15	157 54 45	CPS
3	FORD ISLAND	21 22 00	157 58 00	FDL
4	FT. SHAFTER	21 21 00	157 53 00	FTS
5	HICKAM	21 20 30	157 57 45	HKM
6	KUNIA	21 27 45	158 04 00	KUN
7	LUALUALEI	21 25 45	158 09 45	LLL
8	MAKALAPA	21 22 00	157 56 25	MKL
9	MT. KAALA	21 30 40	158 08 40	MTK
10	PEARL HARBOR	21 21 25	157 57 30	PLH
11	SCHOFIELD	21 29 45	158 03 30	SFD
12	WAHIAWA	21 31 30	158 01 00	WHW
13	WHEELER	21 29 15	158 02 30	WLR

TABLE 6-2.   COMMON USER REQUIREMENTS FOR OAHU, HAWAII

NO.	LOCATION A	LOCATION B	CHANNEL CAPACITY (NO. OF 12.928 Mbps) OR NO. OF DIGROUPS.	DISTANCE (km)
1	BBP	FDL	2	9.8
2	FDL	WHW	1	17.6
3	WHW	HKM	2	21.6
4	HKM	CPS	1	7.2
5	CPS	WHW	1	15.8
6	WHW	PLH	1	16.0
7	PLH	MKL	1	2.4
8	WHW	KUN	2	9.0
9	KUN	HKM	1	18.4
10	WHW	WLR	1	5.6
11	HKM	PLH	1	2.4
12	PLH	CPS	1	7.1
13	CPS	MKL	1	3.7
14	WHW	LLL	1	19.2
15	PLH	FTS	1	8.0
16	WHW	MTK	1	14.8
17	FTS	WHW	1	22.4
18	SFD	WHW	1	6.4
			Total 21	

TABLE 6-3. WIDEBAND USER REQUIREMENTS FOR OAHU, HAWAII

NO.	LOCATION A	LOCATION B	CHANNEL CAPACITY Mbps	DISTANCE (km)
1	WHW	HKM	15	21.6
2	WHW	CPS	15	17.6
3	WHW	PLH	15	16.0
4	WHW	WLR	15	5.6
			Total 60	

TABLE 6-4. NUMBER OF CHANNELS REQUIRED AT EACH
COMMUNICATION NODE IN OAHU, HAWAII

LOCATION	CHANNELS	
	COMMON USER NO. OF 12.928 Mbps	WIDEBAND USER NO. OF 15 Mbps
BBP	2	0
CPS	4	1
FDL	3	0
FTS	2	0
HKM	5	1
KUN	3	0
LLL	1	0
MKL	2	0
MTK	1	0
PHL	5	1
SFD	1	0
WHW	12	4
WLR	1	1
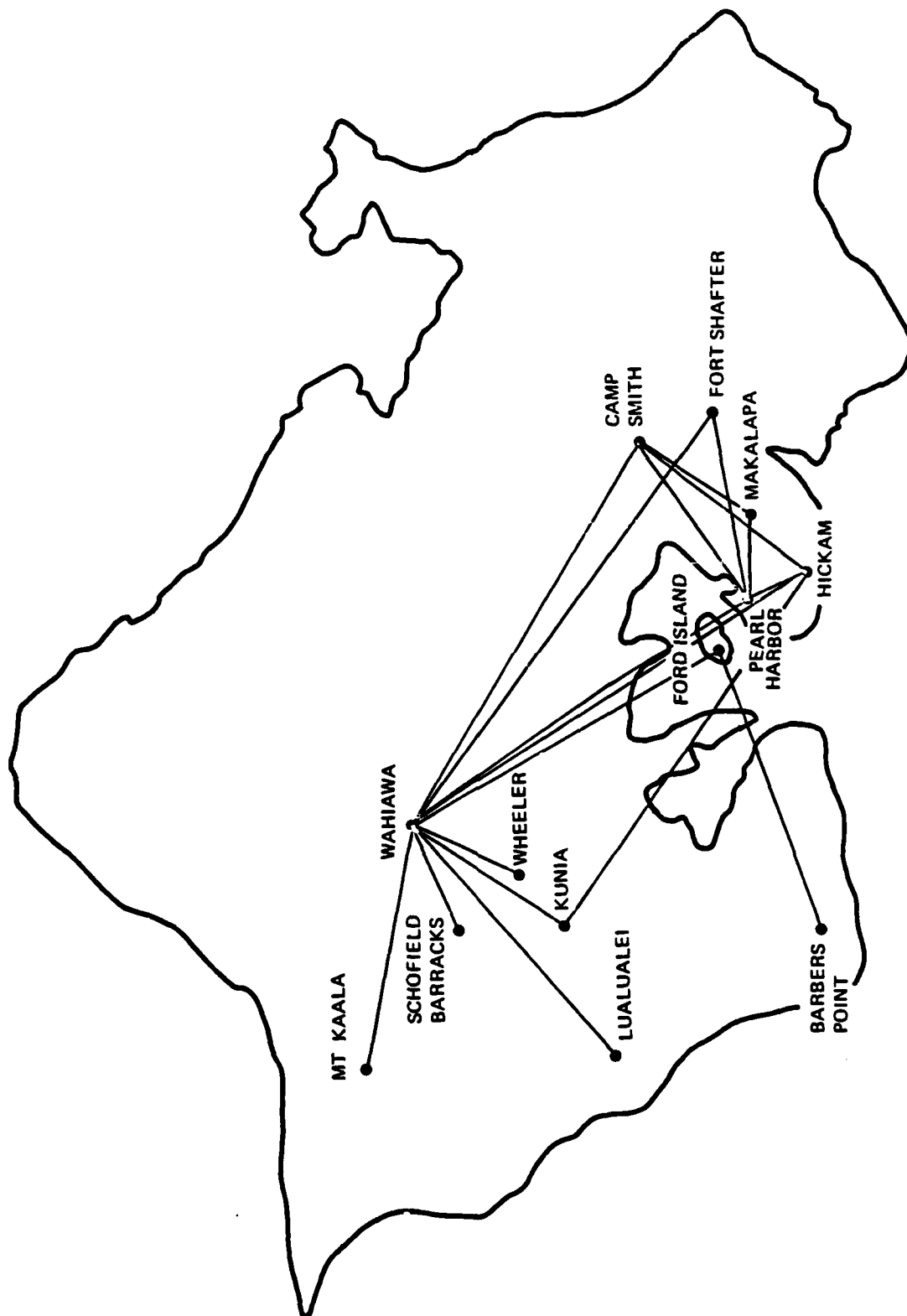
Figure 6-1   Common User Link Connectivity Diagram For Oahu Island
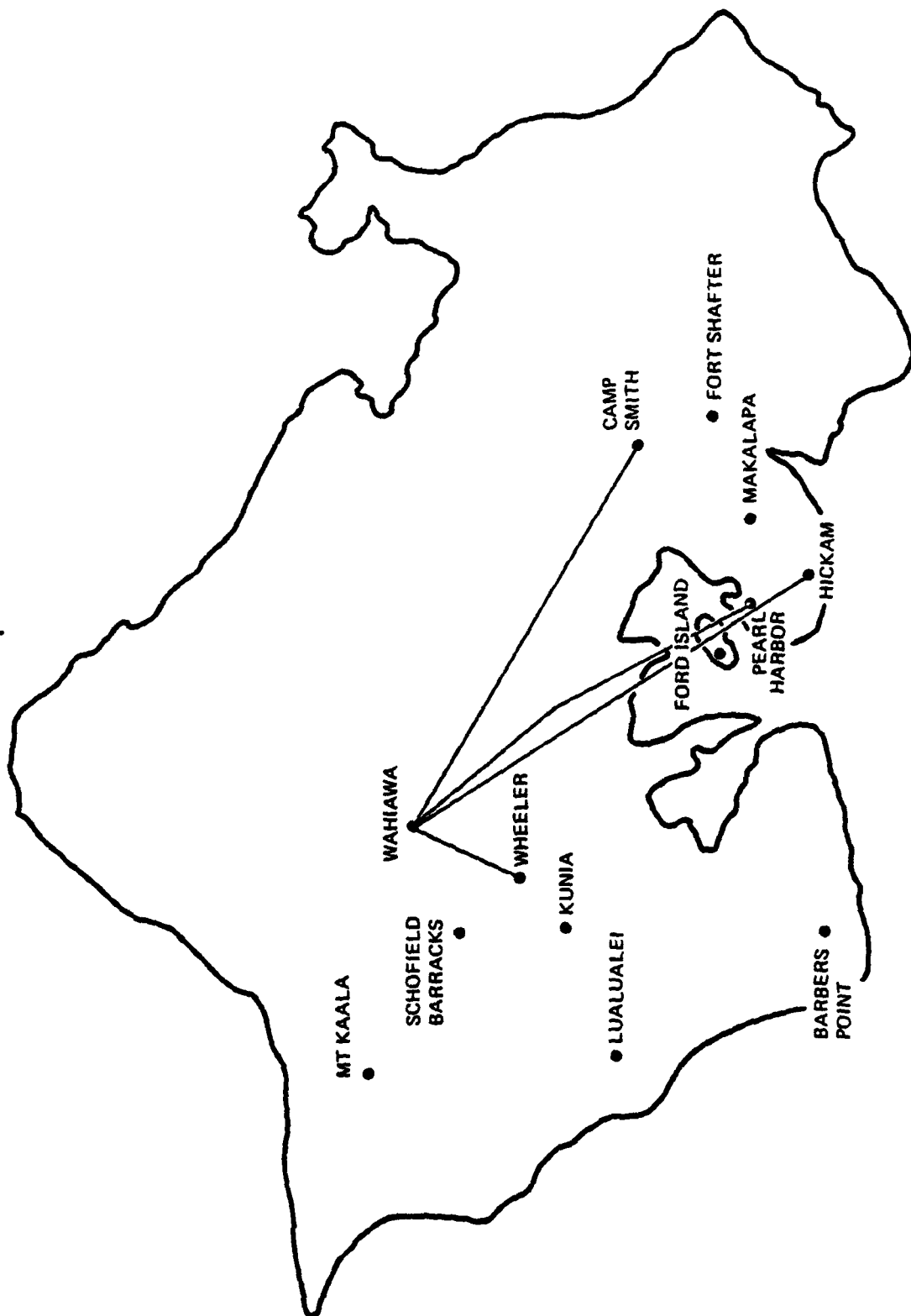
Figure 6-2 Wideband User Link Connectivity Diagram for Oahu Island

6.2 MICROWAVE LOS SYSTEM

Microwave LOS systems are in wide use, the characteristics are well known. The proposed microwave transmission alternative system design is based on the following assumptions.

1. A hypothesized microwave LOS network is proposed as a baseline system meeting the connectivity requirements stated in Tables 6-2 and 6-3.

2. A mesh type network is proposed to increase network survivability and availability.

3. Microwave path lengths will not exceed 80 km. Repeaters are installed on obstructed path or on path length greater than 80 km. Repeater site selection is in accordance with Section 5.1.1-Route and Site Selection.

4. Primary routing for the microwave network will be the most direct routes between two nodes meeting line-of-sight path clearance.

5. Alternative routes are considered for heavy traffic nodes for rerouting and switching purposes.

6. For the five wideband users, each node has at least two alternative routes.

7. Selection of existing radio sites to reduce site construction costs.

The five required wideband users nodes are also common user nodes. There is no reason to provide a separate transceiver sites in these five nodes for common users and the wideband users. It is a reasonable assumption that the wideband user can be accommodated on the existing multiplexers and RF portion.

The proposed microwave LOS network is shown in Figure 6-3. Table 6-5 contains the link connectivity traffic capacity and link distance. Detailed path profile charts are in the Appendix arranged alphabetical by link designation.
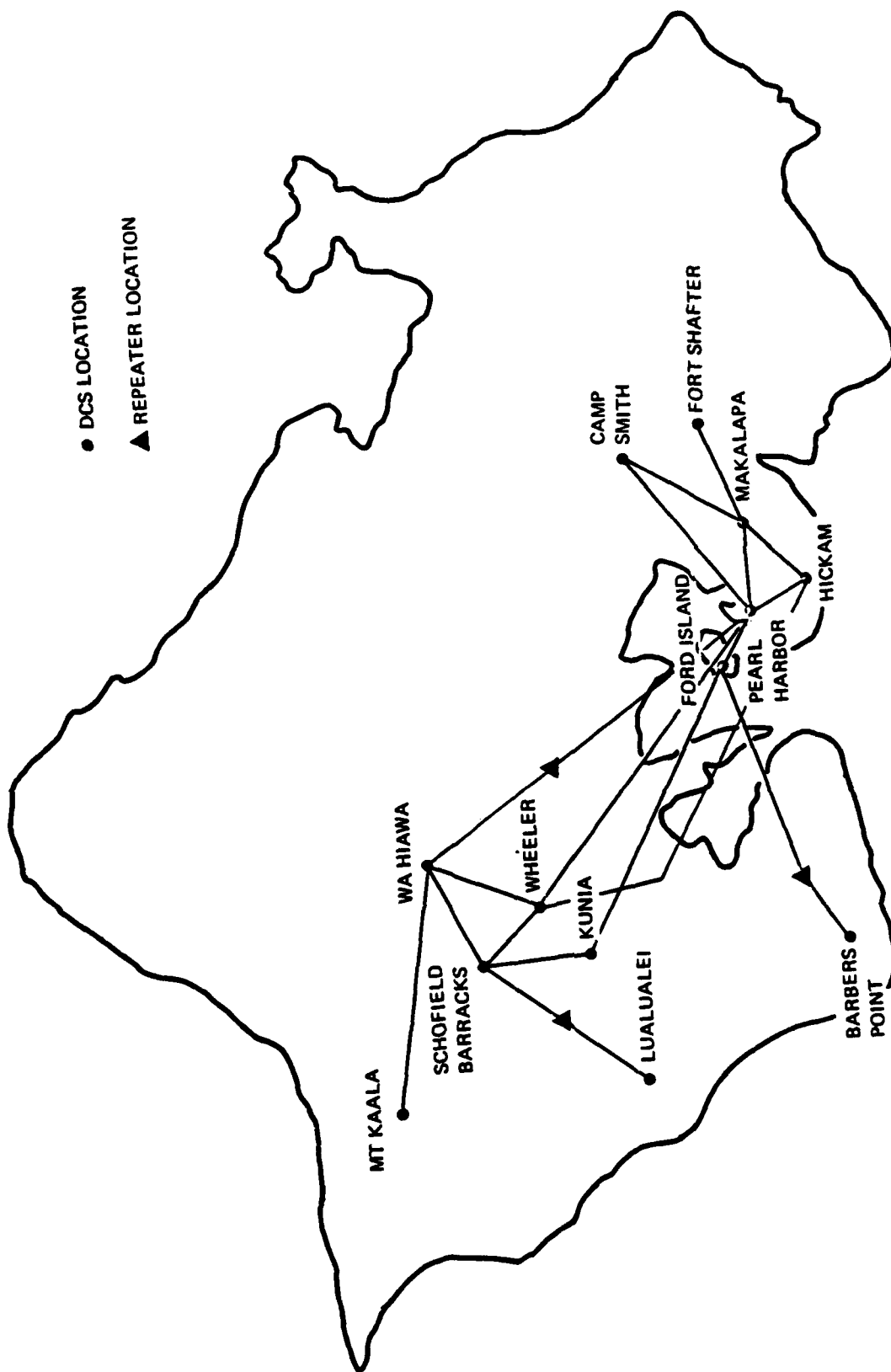
Figure 6-3 Proposed Microwave LOS Network for Oahu Island

TABLE 6-5. CHANNEL CAPACITY ALLOCATION OF
MICROWAVE LOS SYSTEM FOR HAWAII

LINK DESIGNATION	LINK	CHANNEL (NO. OF 12.928 Mbps)	DISTANCE (km)
1	MTL-WHW	2	14.8
2	LLL-LS1*	2	7.1
3	LS1-SFD	2	5.3
4	SFD-WHW	6	6.4
5	WHW-WLR	6	5.6
6	SFD-WLR	3	4.0
7	KUN-SFD	3	3.2
8	WLR-PLH	3	16.1
9	KUN-FDL	3	15.3
10	BBP-BF1*	3	2.3
11	BF1-FDL	3	8.1

TABLE 6-5. CHANNEL CAPACITY ALLOCATION OF
MICROWAVE LOS SYSTEM FOR HAWAII (CONTINUED)

LINK DESIGNATION	LINK	CHANNEL (NO. OF 12.928 Mbps)	DISTANCE (km)
12	PLH-CPS	4	7.1
13	CPS-MKL	3	3.7
14	PLH-MKL	4	2.4
15	FTS-MKL	3	6.4
16	MKL-HKM	2	3.7
17	FDL-PLH	2	2.5
18	WHW-WP1*	6	9.4
19	WP1-PLH	6	10.4
20	WLR-HKM	2	18.0
21	PLH-HKM	5	1.8

* A repeater is designated by three characters, the first two letters
are the first initials of each ending node and the third character
is a number starting with 1. For example; the repeater designation
LS1 connects Lualualei (LLL) and Schofield (SFD).

Some comments on the proposed network are summarized as follows:

1. A total of three repeaters are recommended. The repeaters located between Lualualei and Schofield, and between Wahiawa and Pearl Harbor are recommended due to the nature of terrain conditions and path length constraint. The repeater between Barbers Point and Ford Island is recommended to avoid the RF path across the airfield at Barbers Point.

2. Four nodes Mt. Kaala, Lualualei, Barbers Point, and Fort Schafter are singularly connected. No alternative route is recommended due to the low traffic requirement. The remaining nodes have at least two or more routes. Pearl Harbor, Wahiawa, and Wheeler are the major traffic centers.

3. A total of twenty one links are proposed. The longest link is 18.0 km between Wheeler and Hickam (link 20) with 2-digroup traffic.

4. The heaviest traffic links are between Schofield and Wahiawa, Wheeler and Wahiawa, Pearl Harbor and Wahiawa. Each link supports 6-digroup traffic. It is evident that Wahiawa is the most important node in the network.

5. The channel capacities in Table 6-5 includes at least 20% spare capacity for rerouting capability and future traffic expansion.

6.3 MILLIMETER WAVE LOS SYSTEM

Millimeter wave technology is still in the development stage and has been receiving increasing attention in the past few years. The major restrictions for long distance LOS propagation are atmospheric effects. However, despite all weather range limitations, ever increasing demand for additional spectral space coupled with technology advancements ultimately promise breakthroughs in MM wave LOS communication system development.

A great deal of similarity exists between the millimeter wave
LOS system and the microwave LOS system. The network design assumptions
developed in Section 6.2 are applicable to both systems. However, some
differences exist which impact the network design:

1. The millimeter wave path length is assumed to be less than
    10 km.

2. For the same network connectivity and traffic requirement,
    the number of repeater stations for millimeter wave system
    is more than for a microwave system. Since site construction
    is costly, reducing the number of repeater stations required
    is a prime design task.

3. Since millimeter wave radios operate at higher frequency, smaller
    size antenna, lighter weight equipment, lower power
    consumption. transportability, etc. are the unique features.
    Additionally, the height of a millimeter wave repeater tower
    can be lower than that of a microwave repeater tower.

The proposed millimeter LOS network is shown in Figure 6-4.
Table 6-6 shows the link connectivity, traffic capacity and link
distance. Detailed path profile charts are collected in the Appendix
arranged alphabetical by link designation.

Some comments on the proposed network are summarized as follows:

1. A total of eleven repeaters are recommended. Among them,
    ten repeaters are recommended due to the nature of terrain
    conditions and path length constraints. One is recommended
    to avoid the RF path across the airfield at Barbers Point.

2. Figure 6-4 topology is almost the same as in Figure 6-3
    except for the link between Mt. Kaala and Wahiawa.

3. A total of 29 links are proposed. The longest link (link 16)
    is 8.1 km between repeater BF1 and Ford Island (3-digroup
    traffic).

4. Wahiawa is the heaviest traffic node and is the most
    vulnerable node in the network.
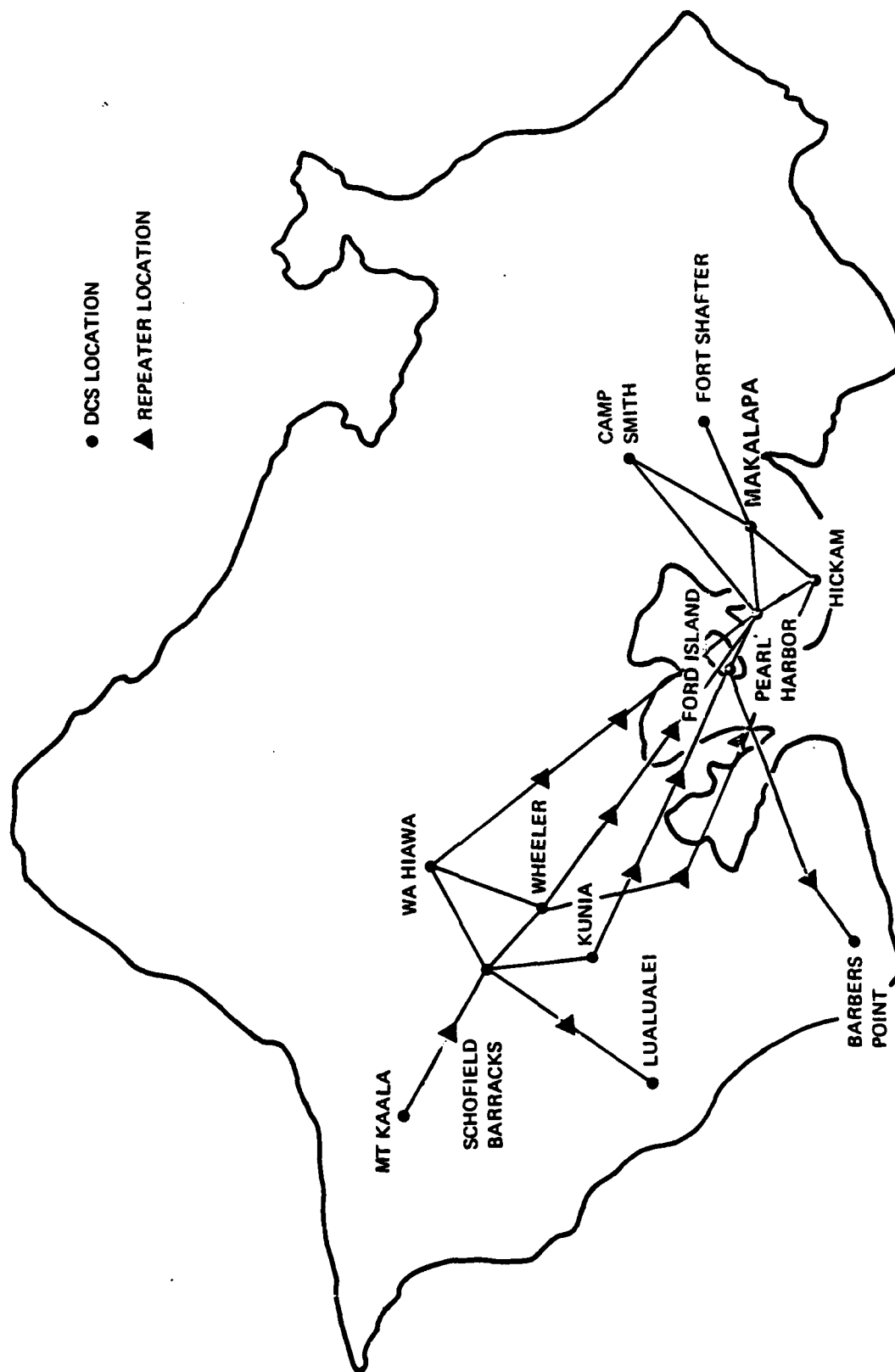
Figure 6-4 Proposed Millimeter Wave LOS Network For Oahu Island

● DCS LOCATION

▲ REPEATER LOCATION

TABLE 6-6. CHANNEL CAPACITY ALLOCATION OF
MILLIMETER LOS SYSTEM FOR HAWAII

LINK DESIGNATION	LINK	CHANNEL (NO. OF 12.928 Mbps)	DISTANCE (km)
1	MTL-MS1*	2	5.4
2	MS1-SFD	2	3.7
3	LLL-LSI*	2	7.1
4	LSI-SFD	2	5.3
5	SFD-WHW	7	6.4
6	WHW-WLR	6	5.6
7	SFD-WLR	3	4.0
8	KUN-SFD	3	3.2
9	WLR-WP1*	3	5.6
10	WP1-WP2*	3	5.6
11	WP2-PLH	3	6.0
12	KUN-KFI	3	4.8
13	KF1-KF2	3	5.6
14	KF2-FDL	3	4.4
15	BBP-BF1*	3	2.4
16	BFI-FDL	3	8.1
17	PLH-CPS	4	7.1
18	CPS-MKL	3	3.7
19	PLH-MKL	4	2.4
20	FTS-MKL	3	6.4

TABLE 6-6. LINK CONNECTIVITY CHANNEL CAPACITY ALLOCATION
AND LINK DISTANCE FOR MILLIMETER LOS SYSTEM (CONTINUED)

LINK DESIGNATION	LINK	CHANNEL (NO. OF 12.928 Mbps)	DISTANCE (km)
21	MKL-HKM	2	3.7
22	FDL-PLH	2	2.5
23	WHW-WP1*	6	7.6
24	WP1-WP2*	6	6.2
25	WP2-PLH	6	6.0
.26	WLR-WH1*	2	5.9
27	WH1-WH2*	2	7.8
28	WH2-HKM	2	6.1
29	PLH-HKM	5	1.8

* A repeater is designated by three characters, the first two letters
are the first initials of each ending node and the third character
is a number starting with 1. For example; the repeater designation
LS1 connects Lualualei (LLL) and Schofield (SFD).

5. The channel capacity in Table 6-6 includes at least 20%
   space capacity for rerouting capability and future traffic
   expansion.

6.4 FIBER OPTIC SYSTEM

A fiber optic system is one of the four alternative systems
proposed for Oahu Island. A communication network design based on
the traffic requirements is shown in Table 6-7.

Assumptions cited in Section 3 are equally applicable here along
with the following additional assumptions.

1. A mesh type network will be proposed to increase
   survivability and availability

2. Repeaterless transmission will be proposed in the network
   design.

3. Cable routes will parallel the existing road network, if
   possible.

4. Alternative routes will be at major traffic nodes.

5. At least two routes shall be considered for the following
   nodes, Wahiawa, Hickam, Camp Smith, Pearl Harbor, and
   Wheeler.

6. In order to save cable installation cost, the common users
   and wideband users may share the same multi-fiber cables
   and same cable routes. However, the multiplexers will
   differ for the two users.

Repeaterless transmission at 850 nm wavelength has already been
demonstrated at 45 Mbps over a span of 55 km. Such performance will
be standard by the year 2000.

Basically, optical fiber cable installation is similar to
conventional cable installation; but major differences do exist. Of
these differences, the most significant is the requirement to handle
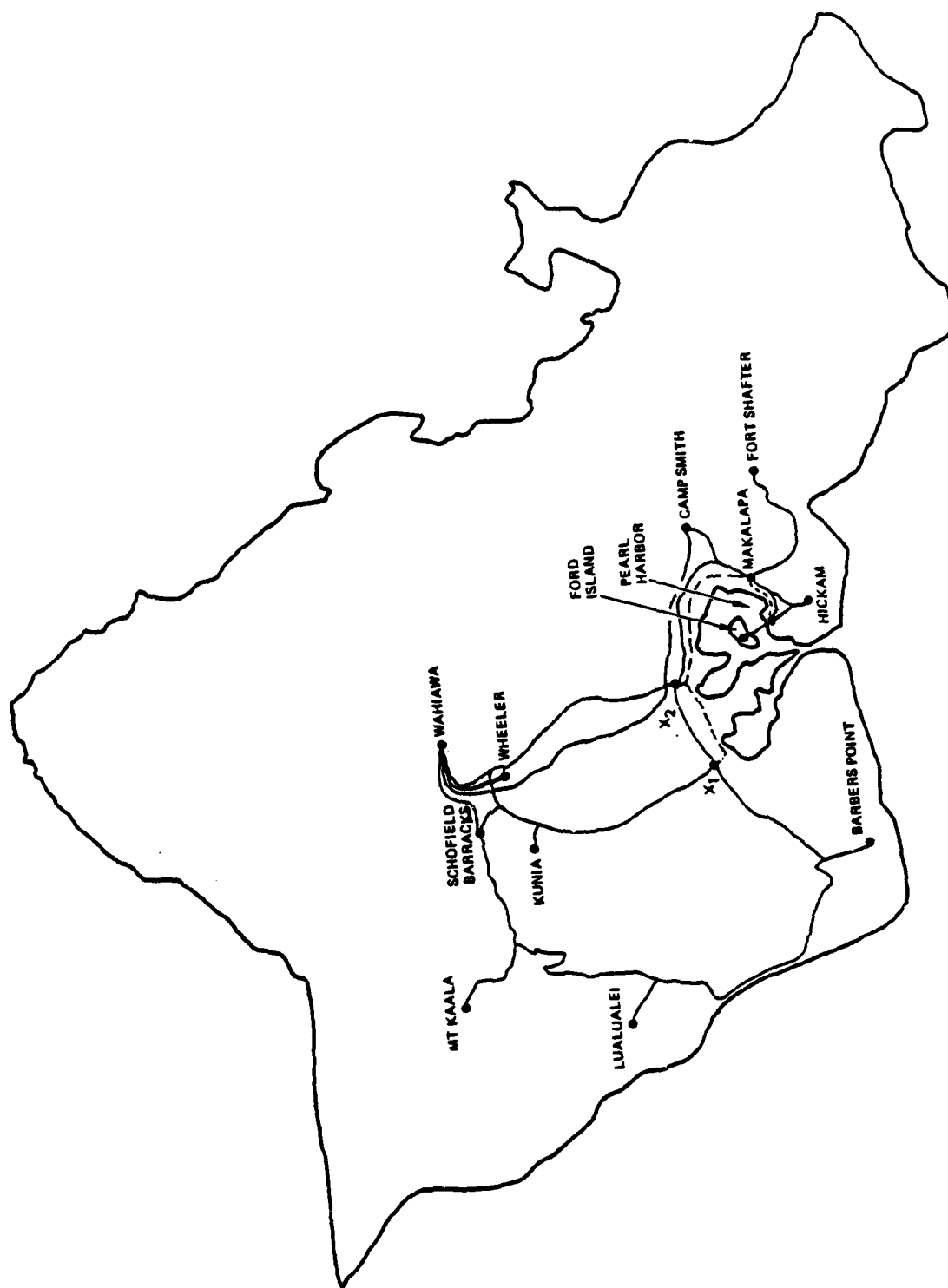
Figure 6-5 Proposed Fiber Optic Network for Oahu Island

TABLE 6-7. CHANNEL CAPACITY ALLOCATIONS OF A
FIBER OPTICS NETWORK FOR HAWAII

NO.	LINK	CHANNEL (NO. OF 12.928 Mbps)	DISTANCE (km)
1	MTL-SFD	2	10.8
2	SFD-WHW	5	9.3
3	WHW-WLR	4	7.7
4	SFD-WLR	1	5.6
5	SFD-KUN	2	4.4
6	SFD-LLL	2	21.7
7	LLL-BBP	1	20.8
8	BBP-X01*	2	11.2
9	KUN-X01	2	8.9
10	WLR-X02*	2	10.4
11	X01-X02	1	4.8
12	X02-MKL	3	10.0
13	CPS-MKL	5	5.0
14	FTS-MKL	3	8.4
15	MKL-PLH	2	3.9
16	MKL-HKM	4	4.0
17	HKM-PLH	3	3.3
18	PLH-FDL	2	1.0
19	X01-X02	3	4.8
20	X02-MKL	2	10.0
21	MKL-PLH	4	3.9
22	WHW-PLH	5	29.4
23	WHW-CPS	4	27.4
		Total	: 226.7

* X01 and X01 are switching and relay stations.

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optical cable in long continuous lengths. Installation in long
continuous lengths minimizes splice loss which occurs when optical
fibers are spliced. Optical cable, small in size and light in weight,
can easily be manufactured in long lengths (up to 100 Km). Optical
fiber cables may be installed on existing pole lines, existing ducts,
or direct burial. Although the cables may be directly buried, it
is advisable to provide ducts in built up areas as an additional
protection against accidental digging. Long lengths, small size
and light weight are substantial advantages for optical cables and
result in significant economy installation when compared with
coaxial cable systems.

In the system design for technology of the year 2000, fiber loss is
considered to be 0.5 dB/km at 1.3 microns and a maximum span without
repeater is assumed to be 50 km. Splice loss will be 0.5 dB each, two
splices are assumed in a link. Connector loss will be 0.5 dB each, four
connectors are assumed in a link. The longest link in Hawaii is less than
30 km, thus only a 12 dB loss will be experienced, no repeaters are
required for the Hawaii network.

Figure 6-5 shows the network topology for the proposed system
and Table 6-7 shows the link connectivity, channel capacity and link
distances.

Some comments on the proposed network are summarized as follows:

1. A total of 23 links are proposed and total cable distance in
    226.7 km. The single longest path 27.4 km is between Wahiawa
    and Camp Smith with a 4 digroup capacity.

2. Two nodes Mt. Kaala and Fort Schafter are singularly connected.
    No alternative route is suggested due to the low traffic
    requirement. The remaining nodes have at least two or more
    routes. Wahiawa, Pearl Harbor, Makalapa and Schofield are
    the major traffic centers.

3. The heaviest traffic links are between Schofield and Wahiawa,
    Pearl Harbor and Wahiawa, Camp Smith and Makalapa. Each
    link supports 6 - digroup traffic. It is obvious that
    Wahiawa is the important node in the network.

4. The link between Ford Island and Pearl Harbor is partially
    underwater. Water-proof cable is recommended.

5. XO1 and XO2 are introduced as switching and relay centers.

6. Redundant links such as between Schofield and Wheeler.
    Lualualei and Barbers Point, XO1 and XO2, are introduced
    to ease traffic and/or provide alternative route.

7. The channel capacity in Table 6-7 assumes at least 20% spare
    capacity in order to have rerouting capability and future
    traffic expansion.

6.5 LEASED COMMON CARRIER SYSTEM

The common carrier in Hawaii is Hawaiian Telephone Company (HAWTEL).
It has been determined that the basic data necessary to design a leased
common carrier system exists within HAWTEL, and hence, was requested.
However, HAWTEL has stated that the requested data is considered to be
proprietary to their approach to the pending Hawaiian Area Wideband System
(HAWS) procurement, and have refused to provide such data.

The possibility of projecting commercial systems suitable for the
DCS III Study, without hard data from HAWTEL, is considered to be of
insufficient credibility for present purposes. Furthermore, without
HAWTEL data, a substantial amount of resources would have to be spent for
generating a common carrier model. These new models would, by necessity,
have to be based on pure "guesstimate" rather than on hard data, thereby
rendering results which could very easily turn out to be totally different
from HAWTEL's plan for the future. To preclude such a possibility, it has
been agreed* that instead of a quantitive design, a "qualitative" description
of the situation in the year 2000 be presented. This description would be
based on the current situation, recent development trends, and forces at
work which will influence the character and quality of commercial
transmission in the interim period. The resulting conclusion is provided
in the following paragraphs and some background and supporting material is
given in the Annex.

*Note: This approach has been adopted at a meeting of the DCA, TRW, and
        Page program managers on 20 July 1981 at TRW DSSG.

It is probable that commercial telecommunications services potentially useful to DCS III on Oahu in the year 2000, will be available in a number of forms. These may fall into three categories:

1. An expanded HAWTEL, providing traditional, plain telephone service, plus enhanced services that are based on upgrades of the traditional telephone system plant. These services will be used by individual subscribers in residences and businesses.

2. A greatly expanded CATV distribution system that provides two-way services to individuals and smaller businesses. Large bandwidths will be available, but the areas (particularly for two-way transmission) will likely be limited to areas comprising the more dense concentration of population.

3. Alternative transmission facilities for larger, high-volume customers. This will break down into subcategories, such as direct on-premises access to satellite (e.g., American Satellite, SBS) and wideband digital local distribution via microwave and millimeter wave radio, circumventing telephone system bottlenecks (e.g., the derivatives of the planned XTEN approach using cellular packet radio).

It is possible that a number of vendors will exist, each offering specialized services of each different form. In such a case, it is likely that there would be overlapping competition for providing the same functional services by different forms, and by multiple vendors; for example, a CATV area network is another obvious way of solving the wideband local distribution problem. It is also conceivable that common vendors could offer all ranges of service forms; for example, HAWTEL could supplement their local distribution plant by offering wideband radio links to their larger subscribers.

Considering just the traditional telephone system, the classical utilization factors will change, as value-added services such as packet-switched data networks proliferate and videotex appears. To support this increased utilization, the bandwidths required in the higher levels of the network hierarchy -- central office and toll trunks -- can be expected to grow significantly faster than just population growth would imply. The early

stages of this trend are apparent in the HAWTEL 1980-1985 plans for trunk facility expansion and fiber optic routes for Oahu, present in Section 1.

In any case, as compared with the situation in 1981, it is reasonable to assume that commercial circuits of much wider bandwidth will be available in the year 2000, and that these circuits might be available from a larger number of vendors, in a wiser variety of forms and over wider areas of Oahu. Over major portions of the projected DCS III network for Oahu, the bandwidths required by DCS III will likely represent a small fraction of bandwidths in place for strictly commercial services, which implies that it would be likely that the DCS III requirements could be at least partially satisfied by leasing part of the available capacity.

One logical and attractive approach would be to establish basic interconnectivities with dedicated DCS-owned assets, which would be supplemented by "backup" circuits obtained by lease from commercial sources. The resulting network would have the advantages to user availability and network survivability of alternate, independent routes, a mixture of media and spare capacity.

The potential suitability of such facilities as part of the DCS III network, however, will require re-examination of some particular issues in the light of the form and nature of these new services. Among these issues are:

1. Policy governing DoD-owned vs. commercially leased facilities in the U.S.

2. Virtual circuits vs. "real" circuits. Particularly those digital services based on advanced concentration and multiple access schemes may not meet the requirements for bit-by-bit synchrony, or bit count integrity.

3. Vulnerability. The physical and architectural characteristics of the facilities underlying some services may be quite vulnerable to interdiction. On the other hand, a multiplicity of relatively inexpensive services would offer the advantages of a mixed-media, alternate routing network.

4. Segregated or dedicated facilities. The degree of segregation of telecommunications components, dedicated only to DCS usage, will also be highly dependent on the nature of each particular service considered.

The relative importance of these issues would depend on whether such commercial circuits were viewed as "primary" or "backup".

It would seem prudent to consider carefully the possibilities of utilizing commercial circuits for a cost-effective network. It is probable that the present unavailability of the data required to develop a quantitative recommendation study is temporary. An effort beyond the scope of the current study should be developed to establish a sound basis for further analysis.

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7.0 CENTRAL GERMANY ALTERNATIVE SYSTEM DESIGNS

Five transmission alternatives are proposed to satisfy common user and wideband user requirements in Central Germany as follows:

1. Microwave LOS

2. Millimeter Wave Radio

3. Microwave and Millimeter Wave Mixture I

4. Microwave and Millimeter Wave Mixture II

5. Optical Fiber Cables

Each transmission alternative is designed to utilize fully optimum medium characteristics and to meet the traffic requirements. These alternative designs are presented in this section, along with requirements and general considerations given in Section 7.1

7.1 REQUIREMENTS AND GENERAL CONSIDERATIONS

The link connectivity and link channel capacity requirements for the common user and wideband user are listed in Tables 7-1, 7-2, and 7-3. For brevity of notation, a three letter designator for each location is listed in alphabetical order in Table 7-1. Almost all radio site locations were found in DCA Circular, DCAC-310-65-1 (Ref. 7-1) and DTIC Report, RADC-TR-79-150 (Ref. 7-2).

In the alternative network design, the intermediate mixture Sets I and II are not limited to using only microwave and millimeter wave. Other media such as cable have been proposed.

Each network evolves from the Digital European Backbone (DEB) System (Ref. 7-3). The DEB network shown in Figure 7-1 covers the area of the locations cited in Tables 7-1 thru 7-3.

As seen in Figure 7-1, the DEB network may be considered as a modified star or tree network. In other words, most of the link connections are heavily concentrated on a small number of nodes, and such nodes play a critical role in traffic control. The advantage of this type of network is cost effectiveness and simple routing procedure due to the small number of switching centers required. The disadvantage of such a network is vulnerability to a threat. In the DEB network, Donnersberg, Koenigstuhl,

TABLE 7-1. SITE DESIGNATORS AND LOCATIONS FOR CENTRAL GERMANY

NO.	SITE LOCATION	LATITUDE			LONGITUDE			DESIGNATOR
1	BAD KREUZNACH	49°	49'	27"	07°	51'	53"	BDK
2	BANN	49	23	55	07	35	18	BAN
3	BAUMHOLDER	49	38	08	07	19	33	BHR
4	BOERFINK	49	43	53	07	05	00	BFK
5	BREITSOL	49	54	10	09	25	46	BTL
6	DARMSTADT	49	50	55	08	39	19	DST
7	DONNERSBERG	49	37	23	07	55	13	DON
8	FELDBERG	50	14	32	08	29	46	FEL
9	FRANKFURT	50	07	41	08	40	15	FKT
10	HEIDELBERG	49	23	12	08	41	00	HDG
11	KAISERSLAUTERN	49	26	40	07	50	30	KLN
12	KARLSRUHE	49	01	59	08	23	39	KRE
13	KINDSBACH	49	25	00	07	37	00	KBH
14	KOENIGSTUHL	49	24	11	08	44	02	KSL
15	LANGERKOPF	49	18	04	07	50	39	LKF
16	LANDSTUHL	49	24	00	07	32	04	LDL
17	LINDSEY	50	04	17	08	13	24	LSY
18	LOHNSFELD	49	24	00	07	32	04	LFD

TABLE 7-1. SITE DESIGNATORS AND LOCATIONS FOR CENTRAL GERMANY (CONTINUED)

NO.	SITE LOCATION	LATITUDE			LONGITUDE			DESIGNATOR
19	MANNHEIM	49°	30'	59"	08°	31'	48"	MHN
20	MELIBOCUS	49	43	32	08	38	17	MEL
21	MUHL	49	40	45	07	01	40	MUL
22	NORTH POINT	49	40	00	07	48	00	NOP
23	PIRMASENS	49	13	01	07	36	35	PMS
24	RAMSTEIN	49	27	04	07	35	04	RSN
25	RHEIN MAIN	50	01	51	08	34	55	RMN
26	SCHWETZINGEN	49	24	31	08	33	40	SWN
27	SECKENHEIM	49	28	00	08	34	00	SKM
28	SEMBACH	49	31	46	07	52	07	SEH
29	WIESBADEN	50	02	30	08	19	35	WBN
30	WORMS	49	38	28	08	21	40	WMS
31	ZWEIBRUCKEN (A)	49	15	55	07	21	51	ZBN
32	ZWEIBRUCKEN (AF)	49	13	48	07	24	02	ZWE

TABLE 7-2. COMMON USER LINK CONNECTIVITY
REQUIREMENTS FOR CENTRAL GERMANY

NO.	LOCATION A	LOCATION B	CHANNEL CAPACITY (T1)	DISTANCE (km)
1	BAN	KBH	6	2.3
2	BAN	LDL	7	4.75
3	BAN	MUL	15	51.4
4	BAN	PMS	16	20.5
5	BAN	RSN	15	6.15
6	BAN	SEH	16	24.75
7	BDK	DON	3	22.5
8	BFK	MUL	7	7.25
9	BHR	DON	11	43.4
10	BHR	MUL	9	22.0
11	DST	MEL	3	14.0
12	DON	HDG	12	60.9
13	DON	KLN	16	21.8
14	DON	LDL	16	37.2
15	DON	LKF	10.5	36.2
16	DON	LSY	3	54.3
17	DON	NOP	2	8.2
18	DON	WMS	5	32.18

TABLE 7-2. COMMON USER LINK CONNECTIVITY
REQUIREMENTS FOR CENTRAL GERMANY (CONTINUED)

NO.	LOCATION A	LOCATION B	CHANNEL CAPACITY (T1)	DISTANCE (km)
19	HDG	SKM	6	12.3
20	HDG	SWN	15	9.17
21	KBH	RSN	6	4.7
22	KLN	SEH	10	10.45
23	KRE	KSL	4	47.9
24	KSL	MEL	5	35.0
25	KSL	MHN	7	19.3
26	KSL	SWN	7	12.5
27	KSL	WBN	2	76.4
28	LDL	RSN	8	7.5
29	LFD	SEH	1.5	2.6
30	LKF	MUL	11	72.3
31	LKF	PMS	13.5	14.5
32	LKF	ZWE	6	33.3
33	MHN	SKM	6	6.1
34	MHN	WMS	5.5	19.3
35	SWN	SKM	6	6.5
36	ZBN	ZWE	5	4.8

TABLE 7-3. WIDEBAND USER LINK CONNECTIVITY
REQUIREMENTS FOR CENTRAL GERMANY

NO.	LOCATION A	LOCATION B	CHANNEL CAPACITY	DISTANCE (km)
1	LDL	BFK	15 Mbps	49
2	LDL	FKT	15 Mbps	116
2	LDL	HDG	15 Mbps	82
4	LDL	RSN	15 Mbps	7.5

Langerkopf and Bann are so heavily interconnected with other cities that paralysis of one of these nodes would result in significant loss of traffic flow capacity.

Donnersberg, especially, typifies the characteristics of the star or tree type network. If Donnersberg loses switching capability, eight interconnections with other cities are disconnected and cities such as Lindsey and Bad Kreuznach become isolated.

Since network survivability under stressed conditions is a major requirement, alternative paths will be provided to improve reliability. At least two alternative paths are required for each wideband user link.

Generally, several specific questions must be considered in overall network design:

1. Topological design. Given the geographical location of nodes and their expected traffic characteristics, where shall the concentration be located? How should they be connected? What form should the network take -- star, tree, loop, mesh, etc.? How many links (connections between nodes) are needed?

2. Line capacity allocation. What trunk size in units of bps or digroup shall be used throughout the network?
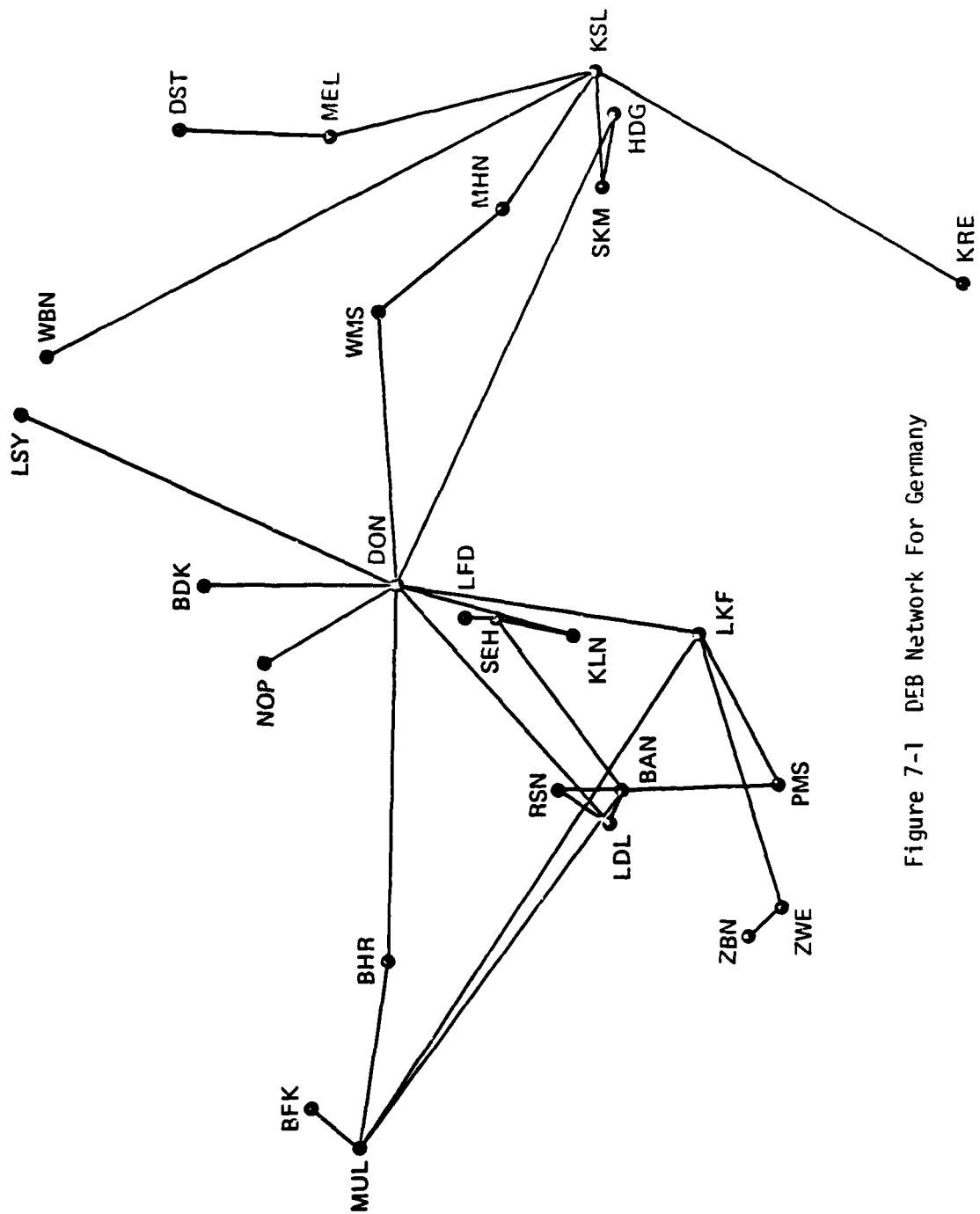
Figure 7-1 DEB Network For Germany

3. Flow control procedures. How are bottlenecks to be prevented? How is smooth traffic flow ensured throughout the network?

In answering these questions, reliability (survivability) and cost are the major criteria. Although performance evaluation in benign and stressed environment and cost estimation are to be addressed in the Task 2 effort, the alternative networks designs of Task 1 must not only meet additional traffic requirements, but must also consider enhanced system survivability and cost effectiveness.

7.2 MICROWAVE LOS SYSTEM

Microwave line-of-sight systems are widely used and the characteristics of the systems are well known. The present system, DEB network, uses microwave LOS equipment except for a few cable links. In this section, a system consisting of microwave LOS only is proposed.

As mentioned in Section 5.1, a microwave link can span a distance of 100 Km without a repeater if enough transmitter power and antenna gain are provided. Actually, some links of the DEB network Stage IV in Central Germany were designed for a distance of more than 110 km without a repeater. For distances less than 80 km and under appropriate terrain conditions, repeaters are not required.

As one of the ground rules in this study in the selection of microwave transceiver sites, existing DEB radio sites are chosen thus avoiding the expensive cost associated with new site construction. Another ground rule is to provide an alternative path for most interconnections. However, some nodes are singly connected due to either limited traffic capacity or very short link distance.

Of the four wideband user nodes; three nodes, Landstuhl, Boerfink, and Heidelberg also service the common user network. There is no reason to provide a separate transceiver site in these three cases for the common user and for the wideband user. It is a reasonable assumption that the wideband user can be accommodated on the existing multiplexers and RF portion. As a result, a separate link network is not needed for the wideband user if a common er link exists.

For each link connection in the network, a path profile is constructed based on the topographic maps and adequate attention to enough margin for each bulge and first Fresnel zone. The path profiles of all links under consideration are illustrated in the Appendix.

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The new microwave LOS network is shown in Figure 7-2. In addition to the nodes shown in the DEB Stage IV configuration in Figure 7-1, three more nodes; Seckenheim, Kindsbach, and Frankfurt are connected in the new network. Table 7-4 briefly explains each link connection in the proposed microwave LOS alternative for the DEB Stage IV network (Figures 7-1 and 7-2).

General comments for the new network are:

1. KRE, does not have an alternative path, as its traffic is minimal.
2. ZBN and LFD also are singularly connected. Their distances from the nearest nodes are very short, less than 5 km, and are located in the same town with the nearest node. Thus, it is assumed that there may be other communication alternatives.

3. For the four wideband user links, at least two alternative paths are provided.

4. Dependence on a few number of nodes in traffic flow is significantly reduced by providing several additional loops.

Finally, Table 7-5 shows the channel capacity allocations for each link in the new network. At least 20% spare capacity is provided in addition to the normal capacity. The spare capacity is used for rerouting of network paths under stressed conditions. However, links KSL-KRE, ZBN-ZWE and LFD-SEH are not allocated spare capacity as they serve only a single end node; KRE, ZBN, and LFD.

7.3 MILLIMETER WAVE LOS SYSTEM

Millimeter wave line-of-sight systems are still in the development stage. Although millimeter wave radios are available for special purposes such as military tactical communications, there is no design for relatively wideband terrestrial relay communications purposes. It is obvious that millimeter wave radios for general purpose communications will be fully developed within this decade.

In this section, we propose a system that consists of millimeter wave LOS only. A millimeter wave LOS system and a microwave LOS system have several common points, however one significant difference is that the millimeter wave is severely attenuated by atmospheric conditions,
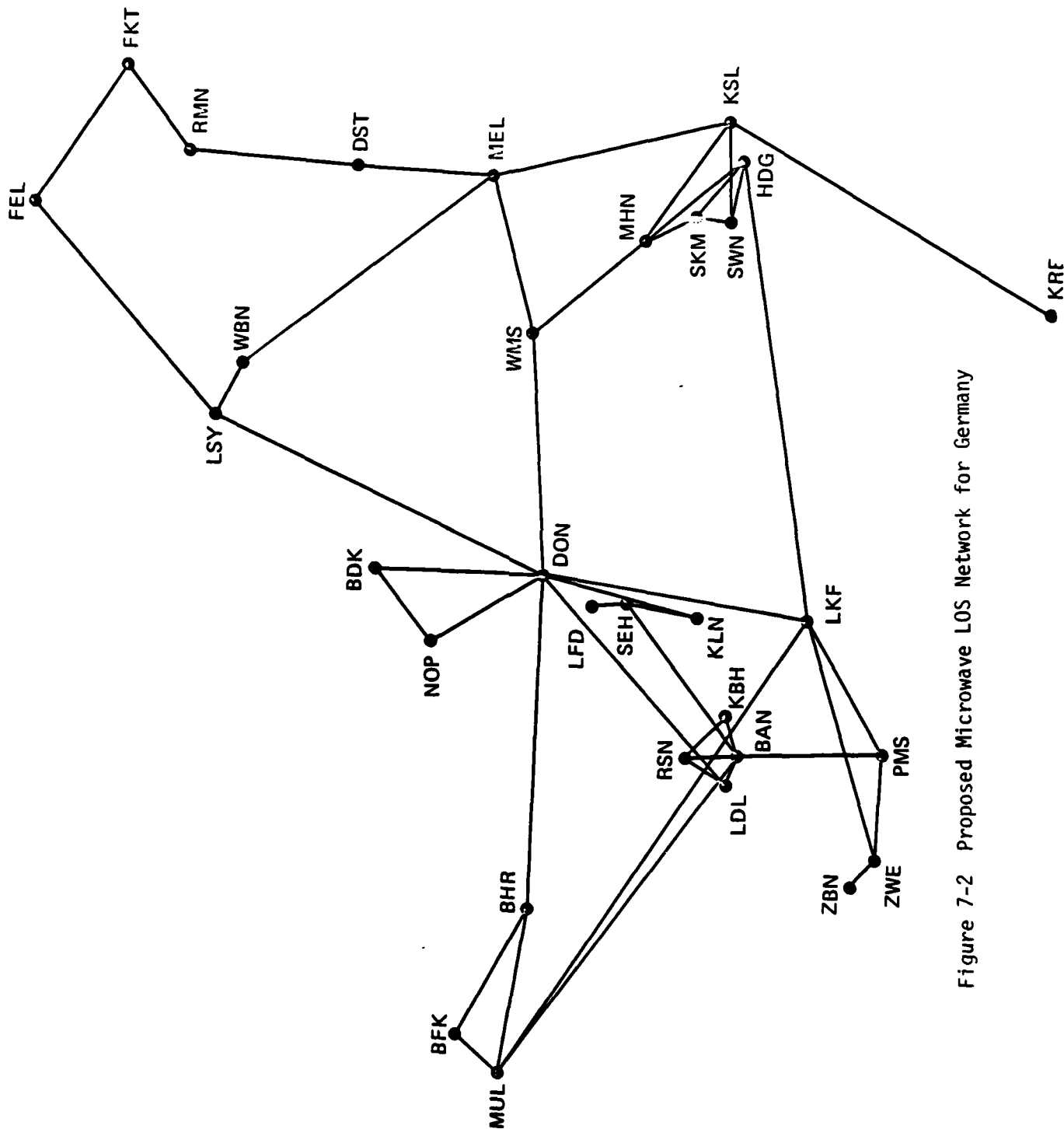
Figure 7-2 Proposed Microwave LOS Network for Germany

TABLE 7-4.   EXPLANATIONS OF GERMAN MICROWAVE LOS LINKS

LINK OR NODE	BRIEF EXPLANATIONS
BFK-BHR	BFK is a node that must connect to LDL for both wideband user and common user. An alternative path BFK-BHR is provided in addition to BFK-MUL-LDL.
KBH	KBH is a new node. Two links, KBH-RSN and KBH-BAN are provided to connect KBH to the network.
ZWE-PMS	ZBN and ZWE are important sites. ZWE-PMS is provided to compliment the ZWE-LKF link.
NOP-DON	Link NOP-DON makes the three nodes NOP, BDK, DON into a redundant loop.
LKF-HDG	HDG and FKT are wideband user nodes connecting to LDL. FKT is a new node in the DEB network. Link LKF-HDG is provided in case node DON is incapacitated. LDL-BAN-LKF-HDG is a direct path to HDG, and also provides an alternative path to FKT. Since DON is so heavily connected, link DON-HDG is eliminated. Link LKF-HDG is the only one requiring a repeater due to terrain conditions.
WMS-MEL	This link makes a loop with KSL and MHN, and also provides an alternative path to SHM, SWN and HDG.
SHM	SHM is a new node. Three paths, SKM-MHN, SKM-SWN, SHM-HDG are provided. Note that four nodes, MHN, SHM, SWN, and HDG also form double loops.
LSY-WBN	This link provides an alternative path to FKT through MEL and DST.
LSY-FEL-FKT	FKT is a new important node. A direct path LSY-FKT is not feasible due to terrain condition, thus existing DEB site FEL is proposed as a repeater site.
DST-RMN-FKT	For the same reason as with link LSY-FEL-FKT, an existing DEB site RMN is proposed as a repeater station.

TABLE 7-5.   CHANNEL CAPACITY ALLOCATIONS OF MICROWAVE
LOS NETWORK FOR CENTRAL GERMANY

NO.	LINK	CAPACITY (T1)	NO.	LINK	CAPACITY (T1)
1	BAN-KBH	8	24	HDG-MHN	13
2	BAN-LDL	30	25	HDG-SKM	16
3	BAN-LKF	12	26	HDG-SWN	20
4	BAN-MUL	30	27	KBH-RSN	6
5	BAN-PMS	19	28	KLN-SEH	12
6	BAN-RSN	18	29	KRE-KSL	4
7	BAN-SEH	20	30	KSL-MEL	10
8	BDK-DON	4	31	KSL-MHN	8
9	BDK-NOP	4	32	KSL-SWN	8
10	BFK-BHR	12	33	LDL-RSN	22
11	BFK-MUL	21	34	LFD-SEH	2
12	BHR-DON	24	35	LKF-MUL	16
13	BHR-MUL	16	36	LKF-PMS	16
14	DON-KLN	20	37	LKF-ZWE	8
15	DON-LDL	30	38	LSY-WBN	4
16	DON-LKF	16	39	MEL-WBN	16
17	DON-LSY	16	40	MEL-WMS	12
18	DON-NOP	3	41	MHN-SKM	16
19	DON-WMS	32	42	MHN-WMS	28
20	DST-FKT	12	43	PMS-ZWE	4
21	DST-MEL	16	44	SKM-SWN	6
22	FKT-LSY	12	45	ZBN-ZWE	5
23	HDG-LKF	12			

especially heavy rainfall. Thus, the millimeter wave link is usually assumed to require a repeater for at least every 10 km. Since site construction costs are the major expense items in a system, network design should minimize the number of repeater stations required. In that sense, if possible, a common repeater tower at one location is proposed to be used to relay signals for more than one link.

Almost all of the millimeter LOS transmitter sites proposed are located at existing DEB sites, however, tens of new repeater stations will be required.

These stations may be implemented at a reasonable cost since millimeter radio equipment is smaller than that of microwave. The height of millimeter wave antenna towers, about 20 m high, are lower than that of microwave systems. In the selection of repeater stations, the following points were mandated:

- Ready access from a major road

- Avoid link traversing highway intersections as high road structures may interrupt the path

- Avoid link traversing metal bridges or large bridges

- Avoid link traversing towns since there may be tall buildings.

As in the case of the microwave network, the loop type of subnetwork is utilized to increase survivability, and no distinction is made between the common and wideband user.

As was discussed in Section 5.2, the proposed millimeter wave radio uses 35 GHz for its carrier frequency, about four times that of microwave. Thus, the millimeter wave can support a bandwidth four times wider than microwave. From a traffic standpoint, it is possible to reduce the number of links if they are destined to close locations or pass through common locations.

The newly designed millimeter wave LOS network is shown in Figure 7-3. Repeater locations and path profiles are provided in the Appendix.

Table 7-6 briefly explains each link connection in the proposed millimeter LOS alternative for the DEB network (compare Figures 7-1 and 7-3). As indicated in Figure 7-3, this network is designed with many small
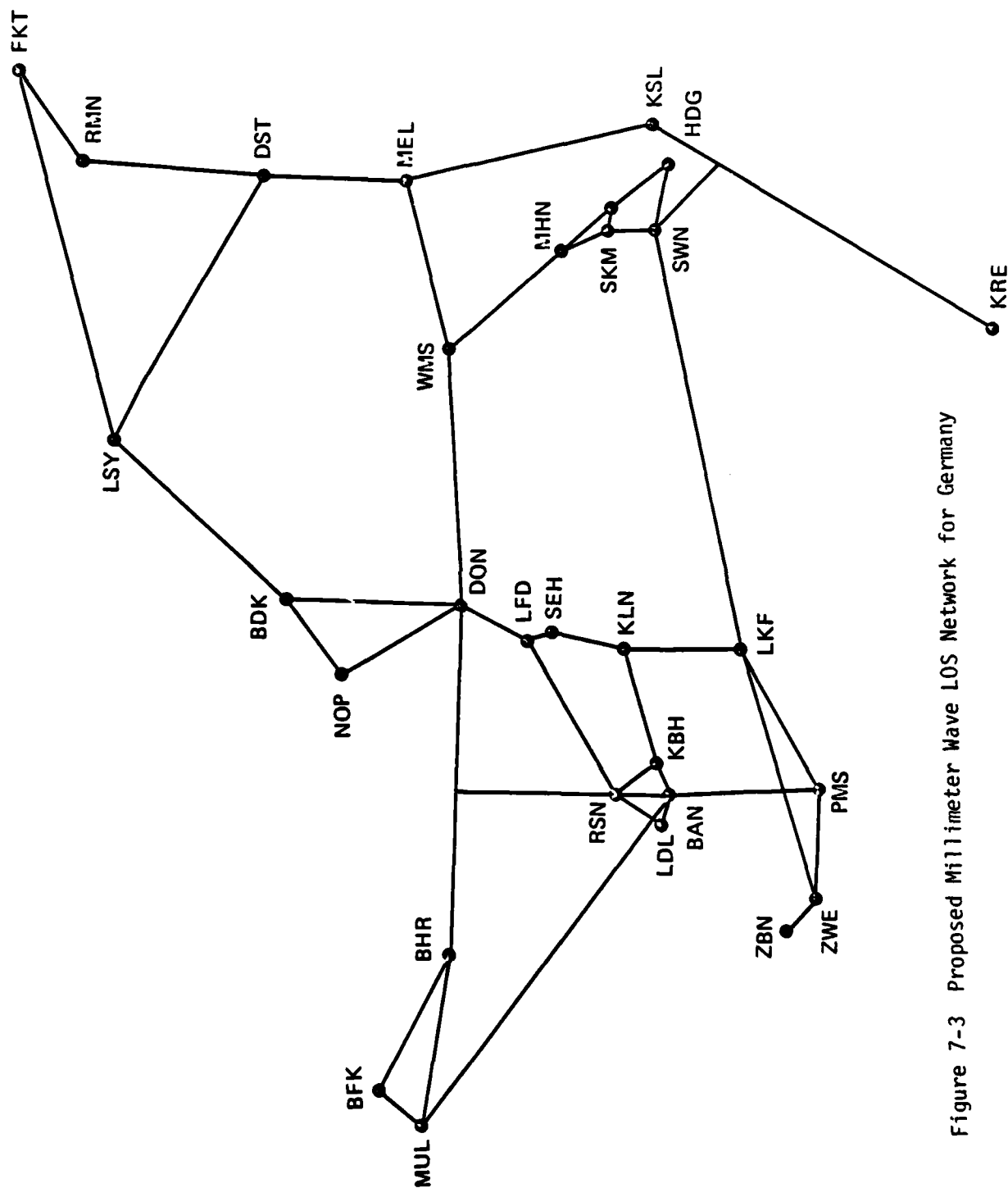
7-13

Figure 7-3 Proposed Millimeter Wave LOS Network for Germany

TABLE 7-6. EXPLANATIONS OF MILLIMETER WAVE LOS LINK
NETWORK FOR CENTRAL GERMANY

LINK OR NODE	BRIEF EXPLANATIONS
BFK-BHR	The same as the microwave case.
RSN-BHR	This link is an alternative path for BAN-MUL, and uses the same repeater station for the link DON-BHR to reduce the number of repeater stations.
RSN-DON	This link is an alternative path for LDL-RSN-LFD-DON, and also uses the DON-BHR repeater station.
DON-LFD	There are three links required from DON: DON-LDL, DON-KLN, and DON-LKF. However, one link, DON-LFD, has been designed to replace these three links using the wideband characteristic of millimeter waves.
KBH	The same as the microwave case.
ZWE-PMS	The same as the microwave case.
NPT-DON	The same as the microwave case.
LKF-HDG	The same as the microwave case, except for the number of repeater stations.
KBH-KLN	This link replaces the link SEH-BAN, reducing the number of repeater sites required.
KLN-LKF	This link replaces the BAN-LKF and MUL-LKF links.
LFD-RSN	To reduce the number of repeaters, this link connects to LDL and DON.
SWN-KSL	The link HDG-KSL was considered as a good choice to connect toward FKT. However, line-of-sight cannot be obtained due to terrain conditions. Thus SWN is routed through the repeater station servicing KSL-KRE to KSL. This link provides another loop network WMS-MEL-SWN-KSL.
MHN-HDG	One repeater station is proposed for this link, also servicing the SHM-HDG link.
WMS-MEL	The same as the microwave case.
SKM	The same as the microwave case.
LSY-WBN	The same as the microwave case.
LSY-FKT	This link is a short cut from DON to FKT.
DST-RMN-FKT	The same as the microwave case.

loop networks to increase survivability, and to reduce traffic flow dependence on only a small number of nodes. This network eliminates several links by using the high wideband characteristics of millimeter waves. Table 7-7 shows channel capacity allocation for each link.

7.4 MICROWAVE AND MILLIMETER WAVE MIX I

The previous two Sections, 7.2 and 7.3, introduced networks in which microwave and millimeter waves are used entirely as transmission media, respectively.

For the purpose of comparison, Section 7.4 and Section 7.5 will provide networks in which various mixes of the two media are used. It is notable that link lengths vary from 2.6 km to 73 km and that some links even with a very short length are rendered not line-of-sight due to the terrain. Thus, utilizing the advantages of each transmission medium, the combined transmission media network can be both more cost effective and more reliable than the single transmission media network.

Advantages and disadvantages of the combined transmission media networks are briefly discussed below:

Advantages

1. It is cost effective compared to the millimeter wave only network because microwaves are used for long links and millimeter waves are used for short links, fully utilizing existing DEB radio sites and reducing the number of repeater stations.

2. It can reduce attenuating effects of the atmosphere on the total networks by utilizing millimeter waves for only short links and microwaves for long links.

3. Frequency spectrum can be more effectively utilized if millimeter waves are used for heavy traffic routes and microwaves are used for light traffic links.

4. It can carry more traffic compared to a microwave only network if millimeter waves are used for the heavy traffic links.

Disadvantages

1. Equipment facilities and logistics must support more than two different media.

TABLE 7-7. CHANNEL CAPACITY ALLOCATIONS OF MILLIMETER
WAVE LOS SYSTEM FOR CENTRAL GERMANY

NO.	LINK	CAPACITY (T1)	NO.	LINK	CAPACITY (T1)
1	BAN-KBH	26	23	HDG-SWN	24
2	BAN-LDL	32	24	KBH-KLN	30
3	BAN-MUL	38	25	KBH-RSN	6
4	BAN-PMS	19	26	KLN-LKF	28
5	BAN-RSN	30	29	KLN-SEH	40
6	BDK-DON	24	28	KRE-KSL	4
7	BDK-LSY	16	29	KSL-MEL	10
8	BDK-NOP	4	30	KSL-SWN	8
9	BFK-BHR	12	31	LDL-RSN	32
10	BFK-MUL	21	32	LFD-RSN	32
11	BHR-DON	24	33	LFD-SEH	32
12	BHR-MUL	16	34	LKF-PMS	14
13	BHR-RSN	16	35	LKF-SWN	16
14	DON-LFD	42	36	LKF-ZWE	8
15	DON-NOP	3	37	LSY-WBN	4
16	DON-WMS	32	38	MEL-WMS	16
17	DST-FKT	12	39	MHN-SKM	35
18	DST-MEL	16	40	MHN-WMS	28
19	DST-WBN	8	41	PMS-ZWE	4
20	FKT-LSY	12	42	SKM-SWN	28
21	HDG-MHN	12	43	ZBN-ZWE	5
22	HDG-SKM	35			

2. There is not enough spare capacity for future planning compared to the millimeter wave only network as the microwave links could bottleneck the network.

As was stated in Section 7-1, the highest traffic capacity requirement for Germany is no more than 25 Mbps, which is a reasonable bandwidth for microwaves. Thus there is no serious reason to use millimeter waves if only traffic requirements are considered.

In this section, fiber optics as an additional media is considered. The following two ground rules are applied for the choice of transmission media:

● Use microwave LOS if there is no repeater requirement

● Use optical fiber (cable) if the link length is short but the terrain is not suitable for line-of-sight communication.

The intermediate mixture network I which is based on that ground rule, is shown in Figure 7-4. One optical fiber link, fifteen millimeter wave links, and thirty microwave links comprise the network. There is no doubt that the network satisfies the link connection requirement of Section 7.1. Table 7-8 briefly states explanations of those links which differ from the previous two networks:

TABLE 7-8. EXPLANATION OF MICROWAVE AND MILLIMETER
WAVE MIX I FOR CENTRAL GERMANY

| LINK OR NODE	BRIEF EXPLANATIONS
HDG-KSL	This is the only link using optical fiber. The terrain condition is not appropriate for either microwave or millimeter wave LOS.
DON-LDL	There are two short paths; one is DON-LDL, a direct connection using microwave LOS link which is the same as that of the microwave network; the other is DON-LFD-SEH-KLN-KBH-BAN-LDL, where half of the path is millimeter wave links and the other half is microwave links. There are two reasons why the first three links use millimeter wave LOS. One is that their link lengths are short enough to be millimeter wave LOS without a repeater, and the other is that they can cover several link connection requirements by using the wideband characteristics of the millimeter wave LOS.

7-18
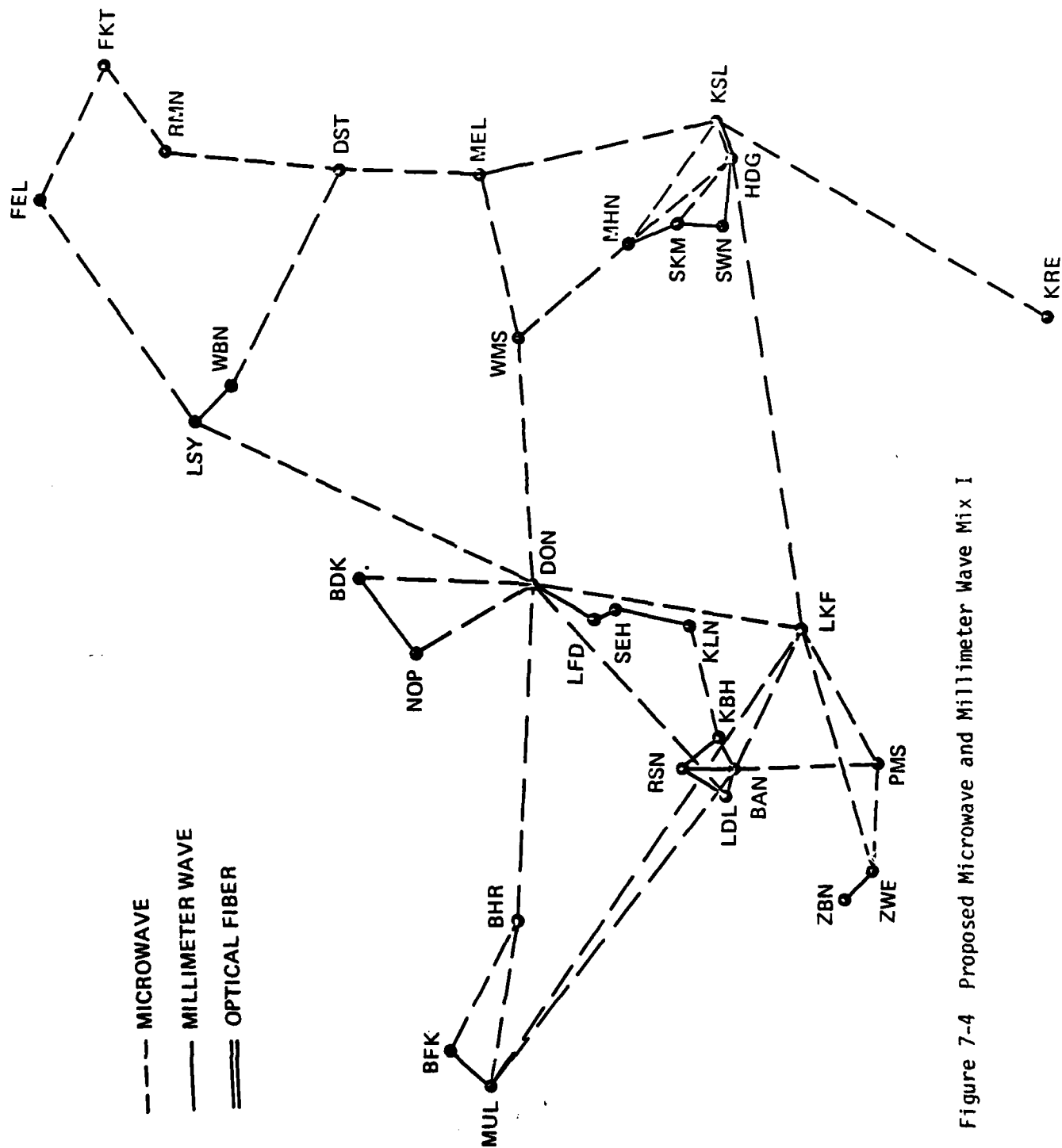
Figure 7-4 Proposed Microwave and Millimeter Wave Mix I

Other connections are the same as for either microwave LOS network of the millimeter wave LOS network. Channel capacity allocations of this mixed system is shown in Table 7-9.

7.5   MICROWAVE AND MILLIMETER WAVE MIX II

As was already mentioned in the previous Section 7.4, this section will also discuss a mixed network of various transmission media. Microwave and millimeter wave will be the main transmission media for this network.

In the mixed network of the previous sections the transmission media were chosen on the basis of the required number of repeaters to connect two nodes. The selection of transmission media in this section is based on not only the required number of repeaters to connect two nodes but also on the reliability of the network. As mentioned previously, a millimeter wave link is not enduring in heavy rainfall. Although heavy rainfall which can attenuate millimeter wave propagation so adversely that the received signal strength falls below the threshold level corresponding to 10^{-4} BER does not occur often (less than 0.1 percent of the year), it is not easy to design a reliable network because the requirements are so stringent.

The network to be designed in this section takes advantage of two characteristics of microwaves and millimeter waves: One is that microwaves are not significantly influenced by atmospheric effects, especially rainfall; the other is that millimeter waves can carry wideband information compared to microwaves. The following ground rules are assumed for the new network design:

1.   Use optical fiber (cable) if the link length is short but the terrain is unsuitable for line-of-sight communications.

2.   Try to reduce the number of links by using the millimeter wave wideband capabilities.

3.   Use millimeter wave LOS for heavy traffic link and/or short length of link.

4.   Provide two alternative paths for critical links such as wideband user links; one path utilizing microwaves, the other utilizing millimeter waves.

TABLE 7-9. CHANNEL CAPACITY ALLOCATIONS OF MILLIMETER
WAVE AND MICROWAVE MIX I FOR CENTRAL GERMANY

NO.	LINK	CAPACITY (T1)	NO.	LINK	CAPACITY (T1)
1	BAN-KBH	26	24	HDG-LKF	12
2	BAN-LDL	30	25	HDG-MHN	16
3	BAN-LKF	12	26	HDG-SKM	28
4	BAN-MUL	21	27	HDG-SWN	20
5	BAN-PMS	20	28	KBH-KLN	22
6	BAN-RSN	18	29	KBH-RSN	6
7	BDK-DON	4	30	KLN-SEH	48
8	BDK-NOP	2	31	KRE-KSL	4
9	BFK-BHR	12	32	KSL-MEL	10
10	BFK-MUL	21	33	KSL-MHN	8
11	BHR-DON	24	34	LDL-RSN	22
12	BHR-MUL	16	35	LFD-SEH	40
13	DON-LDL	30	36	LKF-MUL	16
14	DON-LFD	24	37	LKF-PMS	16
15	DON-LKF	16	38	LKF-ZWE	8
16	DON-LSY	16	39	LSY-WBN	4
17	DON-NOP	2	40	MEL-WMS	16
18	DON-WMS	32	41	MHN-SKM	35
19	DST-FKT	12	42	MHN-WMS	28
20	DST-MEL	16	43	PMS-ZWE	4
21	DST-WBN	8	44	SKM-SWN	28
22	FKT-LSY	12	45	ZBN-ZWE	5
23	HDG-KSL	8			

The newly designed network is shown in Figure 7-5. Table 7-10 briefly states explanations of those links which differ from either microwave or millimeter wave networks.

TABLE 7-10. EXPLANATIONS OF MICROWAVE AND
MILLIMETER WAVE MIX II FOR CENTRAL GERMANY

LINK OR NODE	BRIEF EXPLANATIONS
LDK-BKF	This link is required for both special user and common user, and is heavily loaded. Thus three major alternative paths are provided. One is LDL-BAN-MUL-BFK; the second is LDL-DON-BHR-BFK where BHR-MUL-BFK can be another subalternative path; and the third is LDL-BAN-KBH-KLN-DON-BHR-MUL-BFK. The third one is a complete millimeter wave link which can be used as a main link because it can carry wideband information. The first and second alternatives are mixed millimeter and microwave links so that their total capacities are less than a complete millimeter wave link, but they are more enduring in heavy rainfall and can provide an alternative path for the millimeter wave link.
ZWE-LKF	There are two paths; one is a direct microwave link, ZWE-LKF; the other is a millimeter wave link, ZWE-PMS-LKF. The same reasons apply as in the case of LDL-BFK.
BAN-PMS	There are two paths; one is BAN-PMS, a direct microwave link; the other is BAN-KLN-LKF-PMS, a millimeter wave link.
LDL-HDG	This link is one of the most important. It carries heavy traffic, both common and wideband user. There are several paths available to achieve link connection. One is a complete millimeter wave link, LDL-BAN-KLN-DON-WMS-HDG. Another short path is LDL-KLN-LKF-HDG. It is easily seen that there are more possible link connections in addition to the two main paths. It is obvious that reliability and survivability are deeply considered for this connection.

TABLE 7-10. EXPLANATIONS OF MICROWAVE AND
MILLIMETER WAVE MIX II FOR CENTRAL GERMANY (CONTINUED)

LINK OF NODE	BRIEF EXPLANATIONS
MHN-KSL	There are three main link connections; one is a direct microwave link, MHN-KSL; the second is a millimeter wave and optical fiber combined link, MHN-HDG-KSL; and the third is another combined link, MHN-SKM-SWN-HDG-KSL. Note that there are many small loops to increase survivability.
DON-FKT	This link is required for wideband as well as for common users. One of the wideband links is LDL-FKT. Since the LDL-DON link was already explained in either the LDL-BFK or the LDL-HDG case, the remaining path or LDL-FKT is covered here. There are two short paths; one is a complete microwave link, DON-LSY-FEL-FKT. As explained in previous cases, the microwave link can be used for two main purposes. One is to relay messages for DON-LSY and DON-LSY-WBN; the other is to relay messages for wideband user as an alternative path. Note that LSY and MEL are connected and make the DON-LSY-FKT-MEL nodes form two loops.
HDG-KSL	This is an optical fiber link only because of the terrain condition.

There are fourteen microwave LOS links, twenty-nine millimeter wave LOS links, and optical fiber links in the mixed Network II. This network has more repeater sites than the mixed Network I, but as a trade-off can carry more information.

The following Table 7-11 tabulates the channel capacity allocation of each link.
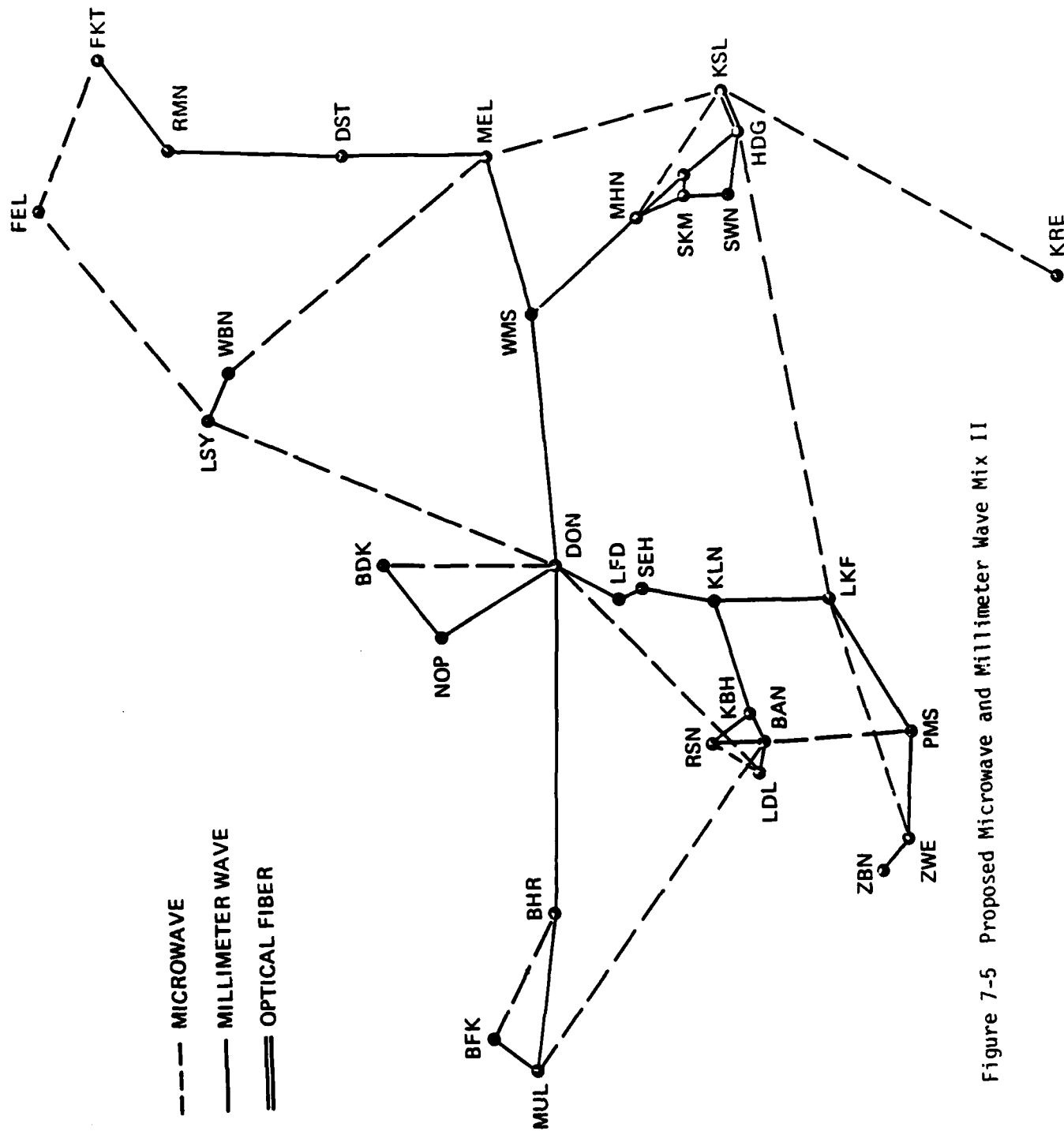
Figure 7-5 Proposed Microwave and Millimeter Wave Mix II

TABLE 7-11. CHANNEL CAPACITY ALLOCATIONS OF MILLIMETER
WAVE AND MICROWAVE MIX II FOR CENTRAL GERMANY

NO.	LINK	CAPACITY (T1)	NO.	LINK	CAPACITY (T1)
1	BAN-KBH	26	23	HDG-SKM	28
2	BAN-LDL	32	24	HDG-SWN	20
3	BAN-MUL	38	25	KBH-KLN	22
4	BAN-PMS	19	26	KBH-RSN	TBD
5	BAN-RSN	18	27	KLN-LKF	28
6	BDK-DON	4	28	KLN-SEH	40
7	BDK-NOP	4	29	KRE-KSL	4
8	BFK-BHR	12	30	KSL-MEL	10
9	BFK-MUL	21	31	KSL-MHN	8
10	BHR-DON	24	32	LDL-RSN	32
11	BHR-MUL	16	33	LFD-SEH	40
12	DON-LDL	30	34	LKF-PMS	16
13	DON-LFD	42	35	LKF-ZWE	8
14	DON-LSY	16	36	LSY-WBN	4
15	DON-NOP	2	37	MEL-WBN	16
16	DON-WMS	32	38	MEL-WMS	28
17	DST-FKT	12	39	MHN-SKM	35
18	DST-MEL	16	40	MHN-WMS	28
19	FKT-LSY	12	41	PMS-ZWE	4
20	HDG-KSL	8	42	SKM-SWN	28
21	HDG-LKF	12	43	ZBN-ZWE	5
11	HDG-MHN	16			

7.6 COST SHARING OPTICAL FIBER SYSTEM

To design a cost sharing optical fiber network with the German
equivalent counterpart of U. S. communications common carriers in the
Federal Republic of Germany -- German Postal Service called Deutsche
Bundespost (DBP) needs some basic data and network information. These
data and information are necessary to provide firm bases for projections
of the evolving architecture, design, and future capabilities of the
Bundespost Telecommunications Network by the year 2000. Numerous attempts
have been made to locate the sources, organizations, and/or individuals
in the FRG and DBP structure for the purpose of obtaining the above
mentioned data and information. These efforts were concentrated on the
Fernmelde Technische Zentralamt (FTZ) and the FRG Ministry of Defense
Offices responsible for liaison with DBP. Despite numerous attempts, the
necessary basic data and network information could not be obtained to
maintain the program schedule.

As an alternative (see footnote on page 6-20), a qualitative overview
as it would possibly exist in the year 2000 is made. Several projections
of the telecommunications in the Federal Republic of Germany in the year
2000 that are relevant to DCS III planning can be made and are given below.

It is highly probable that telecommunications transmission facilities
and services over DBP conventional cable, microwave, and/or new fiber-optic
networks potentially useful to DCS III will be available. These may fall
into the following categories:

1. An expanded and upgraded telephone network providing traditional
   telephone service, plus enhanced new services based on upgrades
   of the current telephone system plant described previously.

2. A greatly expanded data transmission network that provides
   two-way services. Large bandwidths are expected to be available,
   but the areas (particularly for two-way transmission) will likely
   be limited to areas comprising the more dense concentration of
   population in the areas of interest to DCS III.

3. Alternative transmission facilities for large high-volume
   customers to circumvent potential network "bottlenecks", or
   possibly for segregation of military or other sensitive traffic
   type(s).

It is not likely that a number of vendors will be available
(as in the USA), unless the current tradition of DBP monopoly is broken,
-- a very unlikely event at this juncture. But, based on the situation
existing currently, it is probable that the DBP will offer various range(s)
of service forms. For example, the DBP could supplement their distribution
plant by offering fiber-optic and/or wideband radio links to their larger
subscribers.

Considering just the traditional telephone system, classical
utilization factors will change, as services such as packet-switched data
networks proliferate and "Bildschirmtext" appears. To support this
increased utilization, the bandwidths required in the higher levels of
the network hierarchy (i.e., central office and toll trunks) can be
expected to grow significantly faster than just population growth would
imply.

In any event, as compared with the situation in 1981, it is reasonable
to assume that transmission circuits of much wider bandwidth will be
available in the year 2000 and that if the entire telecommunications
network has not been converted to fiber optics by then, at least a
substantial number of fiber-optic cable links will be avialable within the
network. Since over major portions of the projected DCS III network in
Central Germany the bandwidths required will quite likely represent a
small fraction of bandwidth(s) in place for other (commercial) services,
the implications are that it is probable that DCS III requirements could
be at least partially satisfied by leasing part of the necessary capacity.

One logical and attractive approach would be to establish basic
interconnectivities with dedicated DCS-owned facilities which would be
supplemented by "backup" circuits obtained by lease from the DBP. The
resulting network would have the advantages of user availability plus
network survivability of alternate, independent routes, i.e. a mixture of
media and spare capacity.

The potential suitability of such facilities as part of the DCS III
network, however, will require re-examination of some specific policy
issues in the light of the form and nature of these new services. Among
these issues are:

1. Policy governing DoD-owned vs. commercially leased facilities in FRG.

2. Virtual circuits vs. "real" circuits. Particularly those digital services based on advanced concentration and multiple access schemes may not meet the requirements for bit-by-bit synchrony, or bit count integrity.

3. Vulnerability. Physical and architectural characteristics of facilities underlying some services may be quite vulnerable to interdiction. But on the other hand, a multiplicity of relatively inexpensive services could offer advantages of a mixed-media, alternate routing network.

4. Segregated versus dedicated facilities. The degree of segregation of telecommunications components, dedicated only to DCS usage, will also be highly dependent on the nature of each particular service considered.

The relative importance of these issues would depend on whether such commercial DBP circuits were viewed as "primary" or "backup".

It would be prudent to consider carefully the possibilities of utilizing DBP circuits for a cost-effective network. It appears that the present unavailability of the data required to develop a quantitative recommendation study is temporary. An effort beyond the scope of the current study should be developed to establish a sound basis for future analysis.

8.0 SUMMARY AND CONCLUDING REMARKS

The major results presented in this report of Phase II Task 1 of the "Evaluation of DCS III Alternatives" Program are system models, link design methodology and alternative system designs for Oahu, Hawaii and Central Germany fulfilling both common and wideband users requirements.

Four transmission alternatives have been designed for Hawaii, the transmission media used are:

1. Microwave LOS System

2. Millimeter Wave LOS System

3. Optical Fiber transmission system

4. Commercial lease

For Central Germany, the following five alternatives have been designed:

1. Microwave LOS System

2. Millimeter Wave LOS System

3. Microwave and Millimeter Wave Mix I

4. Microwave and Millimeter Wave Mix II

5. Cost sharing Optical Fiber system.

The commercial lease in Hawaii and cost sharing optical fiber system in Central Germany cannot be completed as planned because of difficulties encountered in obtaining needed data. These data are related to current and planned commercial transmission facilities in Hawaii and similar data of the civilian German facilities as indicated in Section 6.5 and 7.6. Instead of quantitative network design, a qualitative description was provided for these two alternatives.

It is worthwhile to point out that the seven alternative designs not only effectively fulfill the required traffic requirements, but each one is provided with a few extra links to improve network survivability.

Since performance evaluation in a benign environment for these alternatives is to be conducted in the Task 2, refinements of system designs in a more definite and detailed manner will be provided in the Task 2 report.

Furthermore, network performance under specified stressed condition will be evaluated in Task II using average network availability (ANA) as a measure. A few modified networks of each alternative will be proposed with their improved ANA for comparison. Then the life-cycle cost of each alternative will be estimated for cost-effectiveness evaluation.

Since all alternatives presented in this report are preliminary and need to be modified and upgraded, therefore, no definite conclusion can be drawn at this time.

A.0 INTRODUCTION

This annex provides background and supplementary material which was used as a base for the conclusions presented in sections 6.4 and 7.5, respectively. These two sections deal with wideband commercial leave on Oahu. Hawaii and cost sharing optical fiber system in Central Germany in the year 2000. The commercial telecommunications have gradually turned out to be an international discipline due to the interfacing requirements among national media for international service and implications of regulations, standards, and recommendations of ITU, CCIR, and CCTT. Therefore, the projected telecommunications situations for these two areas in the year 2000 are quite similar except for certain different national practices.

The information common to these two areas will be presented first, then the material peculiar to Hawaii and Germany.

A.1 THE FORCES THAT AFFECT THE CHARACTER AND QUALITY OF FUTURE TRANSMISSION SYSTEMS

During the last few years a significant amount of interest has developed in integrated telecommunications services; i.e., the provision of telecommunications facilities and services on a subscriber-to-subscriber-basis, capable of supporting a mixture of communication formats such as voice, data, video, text, graphics, and facsimile. Needs for large and small-scale networks are expanding both in traditional telecommunications and in computer-related communications. In computer communications, new applications increasingly involve teleprocessing and require interaction with other applications in a network environment. New applications also mix voice, data, and image transmission and processing. More communication network users will have their own private networks for voice and facsimile as well as data, with integration possible through programmable switches. These systems are being developed as a result of expanding communication capacity and interoperability needs. The telephone, data processing, and office operations are being recognized by management as related functions that must be considered together.

The concept of transmitting different types of communications traffic on a comr circuit is not new. A majority of circuits carrying digital data now are routed over telephone networks that were originally designed for analog voice transmission; the telephone networks, in turn, evolved from early telegraph transmission circuits.

Potential applications of integrated services networks are extrapolation(s) of advanced technology to future service possibilities. However, those applications which represent the most wide-spread potentials, such as the "office of the future," combined home entertainment, communications, remote computing, and telemetering functions, etc., exist at present only in limited or experimental forms. By the year 2000, applications of integrated telecommunications using multiple types of traffic is expected to be incorporated into the same network. Services to private homes will most likely include telemetry for remote meter reading, control of energy consumption, videotex, personal financial transactions, video library and news services, two-way video transmission for educations and "teleshopping," in addition to the currently pervasive telephony and unidirectional video. Integration in offices of the future will quite likely include services and support for remote word processing, data processing, facsimile and electronic mail, audio mail, financial services, voice and video conferencing, and all-electronic file storage/retrieval of voice, data, and image forms.

Table A.1-1 contains a small sampling of these applications; numerous other possibilities have been detailed in the literature. As "far out" as some of these projections may seem now, there are undoubtedly other possibilities completely unforeseen, and some of today's predictions will seem hopelessly archaic by the turn of the century.

A.2 TECHNOLOGY AND COSTS

Cost reduction is probably the most powerful motivation for change and improvement, while technology is usually the mechanism for achieving the cost reduction. Even in the simplest of situations, economics and technology are strongly related; however, when considering integrated services, the relationships become quite complex. Nevertheless, the primary trends can be discerned.

Table A.1-1. A SAMPLING OF INTEGRATED NETWORK APPLICATIONS

GENERAL COMMUNICATION

      Electronic Mail, Messages
      Teleconferencing
      Speech
      Encrypted Speech
      Still Pictures
      Moving Pictures

ELECTRONIC OFFICE AND WORK ASSISTANCE

      Remote Work via Telecommunications Terminals
      Computer Enhanced Output Quality
      Computer Assisted Task Management and Coordination

MANAGEMENT

      Farm Management Services
      Data Collection
      Computer Assisted Problem Solving and Decision Making
      Modeling

COMMERCE

      Electronic Markets and Auctions
      Computerized Commerce
      Employment Services
      Electronic Fund Transfer, Banking Services
      Remote Shopping

PROFESSIONAL

      Monitoring Patients and Population Groups
      Remote Medical Consultation and Diagnosis
      Medical Records
      Medical, Legal, and Other Knowledge Data Bases

GOVERNMENT

      Military Command, Control, and Communications
      Logistics
      National Crime Information Center
      Social Security

PROTECTION

      Home and Business Security -- Fire and Burglar Alarms

EDUCATION, INFORMATION, AND ENTERTAINMENT

      Computer Assisted Education
      Customized News Selection
      On-Request Television Programs
      Video Games
      Remote Instruction and Interactive Training

Long-haul communications costs have been decreasing at a rate of about 11 percent (real cost) per year and processing costs have been dropping at about 25 percent per year. The decline of these two cost figures is the major impetus behind the burgeoning application of teleprocessing and distributed processing systems.

Communications costs, in the sense of classical transmission, have been declining primarily because of advent of communication satellites. This cost trend can be expected to continue because of:

1. More efficient utilization of transmission capacity, such as by employment of demand-assigned TDMA satellite technology

2. Continued movement toward digital transmission, with attendant lower life-cycle costs

3. Widespread implementation of another new technology -- optical fiber transmission -- making available very large bandwidths.

The main reason for the decline in processing costs is the advance of large-scale integrated circuits (LSI) technology, in the areas of digital circuits, computers, and specialized computer-like functions. LSI chips are now available which enable low-cost implementations of communications functions, such as analog-to-digital and digital-to-analog converters, amplifiers, filters, modems, and line interface circuits; these devices are necessary for the realization of fully integrated digital services (e.g., analog-digital conversion of voice) and for the hybrid techniques required in the transitional stages of integration (e.g., modems).

Since the cost decline is in real terms, there is strong incentive to substitute telecommunications/teleprocessing applications for traditional labor intensive services whose costs have been rising rapidly, or those that involve significant expenditures of energy. One example is electronic mail; somewhat more exotic examples are those applications that substitute for increasingly expensive travel, such as teleconferencing, work stations in the home, or teleshopping. Additionally, processing costs, as mentioned earlier, have been decreasing at a rate of about double that for communications. As a result, the classical distinction between the communications functions of transmission and those of switching is becoming increasingly "fuzzy" as digital processing techniques invade telecommunications functions to achieve

greater efficiencies; thus, digital computers are being assimilated rapidly
into the communications process, and additionally, computers are also
increasing in numbers as "users" of communications. The combination of these
two developments further support the trend towards incorporating digital
technology in telecommunications.

A.3 DIGITAL TRANSMISSION

Implicit in the long-term future of integrated services networks are
all-digital transmission circuits and facilities. Besides the consideration
of integrated services, digital technology is rapidly supplanting older
analog technology in most areas of telecommunications networks. In general,
economic advantages center on three factors:

o   Lower overall system costs, due to integration of functions and
      processing,

o   Lower allocated costs, because of greater flexibility and
      efficiency of digital multiplexing, concentration, and switching
      functions,

o   Lower maintenance costs, because of greater reliability of digital
      equipment.

In general, any traffic an be transmitted in either digital or analog
form. Information that is intrinsically digital (e.g., computer input/
output) is obviously better matched by digital transmission. On the other
hand, information which interfaces with humans is usually in analog form
(e.g., voice and images); hence, it must be converted to digital form for
digital transmission and reconverted after reception for presentation to the
user. But the quality of digital transmission is normally superior to analog
transmission, even for analog information, as evidenced by typical values of
signal-to-noise ratio, error rate, and distortion.

The economic and technical advantages of digital transmission in many
instances are sufficient, even at present, to offset the costs of processing
necessary for analog/digital conversion, and they are expected to improve
further in the future. Relatively rapid conversion to digital transmission
is proceeding in the high-volume trunking (as well as switching) area, where
major economic advantages exist. Transmission facilities of increasingly

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wider bandwidths offer previously unattainable economies of scale. This trend is extending to intermediate network levels, as demonstrated by large digital central offices and wideband (optical fiber) inter-office trunks.

An important technological trend, that is tightly coupled with the development of integrated services, is the appearance of new network architectures which is made possible by digital techniques. For example, packet switching, on global and/or local basis, and time-division multiple access (TDMA) techniques promise greater efficiency in the utilization of wider bandwidths, which will become increasingly available for fully integrated services.

A.4 ECONOMIES OF SCALE

Terrestrial microwave radio, communications satellite, coaxial cable, optical fiber, and other wide bandwidth transmission media offer economies of scale when their large bandwidth can be well utilized. In some cases, capacity requirements of any single traffic type are insufficient and, therefore, traffic must be combined to justify use of a wideband medium. Combination is achieved by multiplexing, concentration, or switching techniques.

Economy of scale is vividly illustrated by a comparison of cables with fiber-optic transmission. In cable transmission, ten circuits have a relative cost of over $200 per circuit mile. In fiber-optic transmission, investment cost per circuit may well be under $2 per mile when 10,000 or more circuits are installed.

Thus, the integration of telephone and television transmission facilities over fiber optic networks offer economies for rural and suburban areas, which will quite likely be utilized in the not too distant future. Additionally, since processing overhead and system complexity can be reduced where the necessary bandwidth is available, one obvious approach (which will probably occur) is to design for sufficient "excess" bandwidth to provide adequate grades of services for all users. This excess bandwidth can be made available at the same, or even lower, marginal cost when the traffic is combined because of the "economy of scale."

Traffic integration will provide additional benefits in those areas where the combining of traditional telecommunications with computer and other types of communications is necessitating common management, because oppor-

tunities can be recognized and acted upon with less complication when the separation of normal telecommunications and computer communications in organizations is no longer maintained.

A.5 FACILITIES OF HAWAIIAN TELEPHONE COMPANY

The common carrier serving Oahu, Hawaii is Hawaiian Telephone Company (HAWTEL). The information provided by HAWTEL is limited to the following figures and tables. These Figures A.5-1 to A.5-3 indicate the existing Oahu trunk facility, Oahu trunk facility expansion (1980-1985), and programmed fiber optic routes. The schedules of trunk facility expansion and fiber optic routes are in Tables A.5-1 and A.5-2, respectively.

A.6 NATIONAL REGULATORY TRENDS

The current regulatory environment is in foment, with strong technological economic and political pressures at work. Some of the key drivers have already been mentioned. One recent result is the landmark decision by the Federal Communications Commission on Docket 20828, "Computer Inquiry II," which effectively puts communication services more sophisticated than "pure" transmission or "plain old telephone service" (POTS) beyond the regulatory pale. The basis of the decision was the inability (after nearly a decade of effort) to draw clear lines of demarcation, defining where (regulated) communication services stop and (unregulated) processing services begin. The profound impacts of this decision, if allowed to stand intact, are just beginning to be realized.

In the meantime, the encouragement of competition, innovation, and even entrepreneurship in the telecommunication industry has become as almost completely accepted matter of policy. The movement, whose first glimmer was the Carterfone decision in 1968, continues on its crescendo, with new carriers appearing almost yearly, and value-added services in some form being announced daily. Each of the branches of government -- executive, legislative, and judicial -- is vying to impose its stamp on the formulation of the results; but all agree on the general direction.

Barring a reversal in course even more dramatic than the events of the last decade, a variety of forms and suppliers of telecommunications services will be available throughout the USA in the year 2000. The same can be expected in the "special cases" of Alaska and Hawaii.
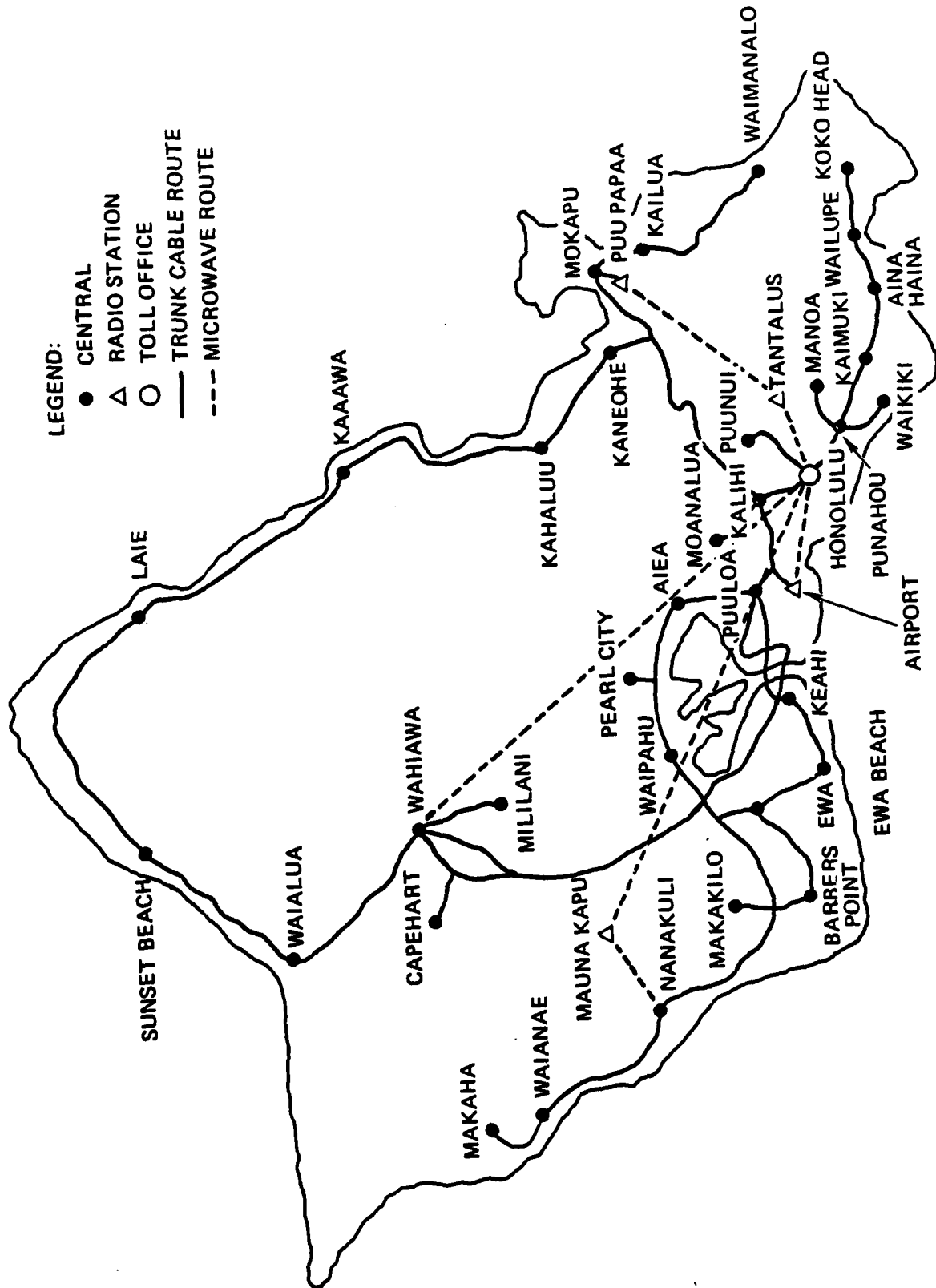
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LEGEND:
● CENTRAL
△ RADIO STATION
○ TOLL OFFICE
— TRUNK CABLE ROUTE
--- MICROWAVE ROUTE

Figure A.5-1. Existing Oahu Trunk Facility (Year End 1979)

LEGEND:

● CENTRAL OFFICE
△ RADIO STATION
○ TOLL OFFICE
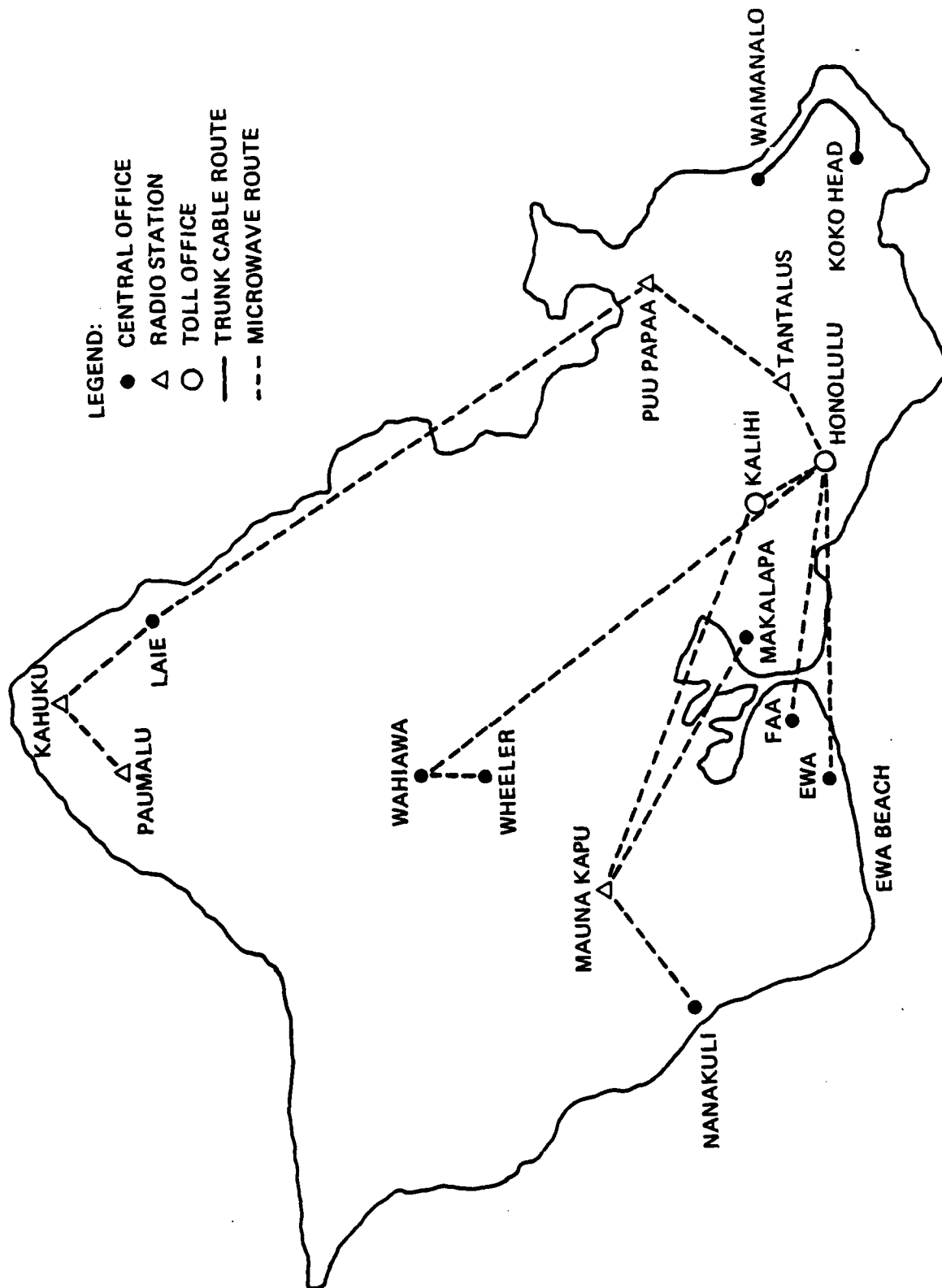—— TRUNK CABLE ROUTE
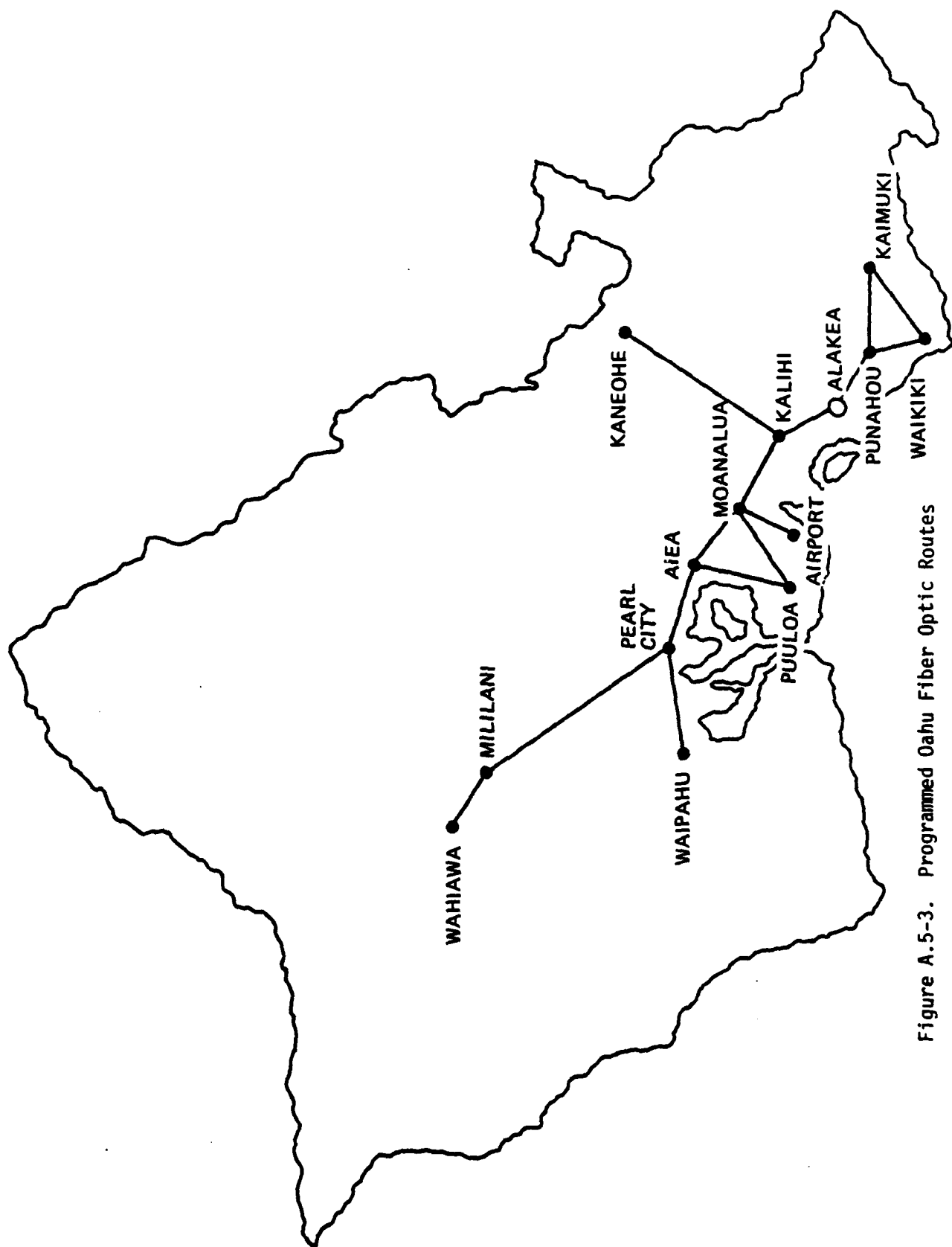- - - MICROWAVE ROUTE

Figure A.5-2. Oahu Trunk Expansion Program (1980-1985)

Figure A.5-3. Programmed Oahu Fiber Optic Routes

Table A.5-1. SCHEDULE OF OAHU TRUNK FACILITY EXPANSION (MICROWAVE)

TRUNK	YEAR
Puu Papaa - Laie - Kahuku - Paumalu	1980
Puu Papaa - Tantalus	1980
Makalapa - Mauna Kapu	1980
Tantalus - Honolulu	1981
Honolulu - Wahiawa	1982
Honolulu - Ewa Beach	1983
Tantalus - Kalihi	1985
Honolulu - Kalihi - Mauna Kapu - Mankuli	1985
Honolulu - FAA EWA	1985

Table A.5-2. SCHEDULE OF FIBER OPTIC ROUTES

ROUTE	YEAR
Alakea - Kalihi	1979
Alakea - Punahou	1980
Kalihi - Moanalua - Airport	1981
Pear City - Mililani	1981
Waikiki - Punahou	1982
Moanalua - Puuloa	1982
Pear City - Aiea	1982
Moanalua - Aiea - Puuloa	1983
Pear City - Wahiawa	1983
Punahou - Kaimuki	1984
Kaimuki - Waikiki	1985
Kalihi - Kaneohe	1985

A.7 FRG GOVERNMENT, DBP ORGANIZATIONAL STRUCTURE, AND THEIR INTERACTIONS

The Federal Republic of Germany (FRG) is a federation of ten autonomous states (Lander) plus West Berlin. Executive power is vested in the states, except where the constitution prescribes or permits otherwise. For example, state and local governments determine their expenditures independently (unless the central government invokes contingency clauses of the constitution).

The two-tier German parliamentary legislature consists of an elected "Bundestag" and a "Bundestrat," whose members are appointed by state governments according to each state's population. A Federal Assembly meets every five years to elect the President who represents the country in international relations. The federal government, which includes federal ministers appointed by the President, is headed by a Chancelor elected by the Bundestag. The federal government legislates, among other things, foreign affairs, trade with foreign countries, federal railways, air traffic, posts and telecommunications, and customs.

Germany is Western Europe's strongest economic power, with the third largest GNP of any non-Communist country. Its per capita GNP now exceeds that of the United States. It is highly industrialized, and is notable in particular for its manufacturing industries and as an exporter of manufactured goods. FRG membership in the European Economic Community (EEC) has a strong influence on its commercial relationships.

Since the greatest portion of FRG's trade is with its European neighbors, principally with other members of the European Economic Community (EEC), the bulk of its communications traffic is with those nations. The currently existing telephone network is fully automated (since 1972), and all subscribers have access to international direct dialing. As a result, the entire system must, by necessity, conform to a significant extent with the evolution of telecommunications systems in other EEC member countries.

The government-owned/operated telecommunications carrier, the Deutsche Bundespost (DBP), is the responsibility of the German Federal Government, but the individual states are intimately involved in questions and decisions connected with such new services as cable television, broadcasting, and other services such as interactive viewdata, etc. Overall authority of telecommunications is vested in the Federal Minister for Posts and Telecommunications

(Bundesminister fur Post and Fernmeldewesen). This authority derives from the Telecommunication Equipment Law (Fernmeldeanlagengesetz) of 1977, which also assigned administrative responsibility for telecommunications to the Deutsche Bundespost (DBP). Subsequently, the Postal Administration Law (Postverwaltungsgesetz) extended and specified the responsibilities of the Federal Minister for Posts and Telecommunications.

A peculiarity of the DBP lies in the area of finance; unlike most other European PTTs, the DBP cannot obtain direct government funding. The federal fund for PTT services is acquired from the operation of these services, and is kept separate from other federal government funds.

There are three levels of organization in the Bundespost. At the national level is the Ministry of Postal Telecommunications Affairs, the central regulatory and policy-making body. It is organized into administrative and operational divisions and offices under two Secretaries of State. At this top level, there is also an executive committee which (in accordance with the postal administrative law) reviews DBP plans, approves year-end reports, and approves the rates and conditions for services of the DBP. The *second-level organization of the Bundepost comprises the Postal Engineering* Center (Posttechnische Zentralamt -- PTZ), the Telecommunication Engineering Center (Fernmeldetechnische Zentralamt -- FTZ), the Bundepost Welfare Office, the Bundepost Engineering Academies, and 18 Regional Post and Telecommunication Directorates throughout the country. Within their areas, the Regional Postal and Telecommunication Directorates manage the entire administration of postal and telecommunication services.

The principal objectives of the Telecommunications Engineering Center (FTZ), which is headquartered in Darmstadt, are to provide:

o   advice on the development of telecommunication systems and equipment;

o   regulatory and pricing policies;

o   coordination of international cooperation in telecommunications;

o   research in communications.

Despite the overall authority of the Bundespost Ministry, the FTZ is in fact the "executive" body concerning telecommunications; it is headed by a President who has a permanent representative, a Vice President, an Internal Administration Department, and four Heads of Department. The Departments are responsible for the preparation of short and long term objectives, establishing general principles, proposing solutions to fundamental questions and coordinating comparable technical developments within their areas of responsiblity which are as follows:

o   Principal Department A: Cable-based telecommunications techniques

o   Principal Department B: Telecommunication services, acquisitions, operational matters

o   Principal Department C: Telecommunication networks, radio

o   Principal Department D: Organization and electronic data processing for telecommunications

o   The Research Institute of the DBP (formerly known as Principal Department D): Determination of future techniques, analysis of technical development at both national and international level.

The Bundepost is the major purchaser of telecommunications equipment; it is also the authority that regulates the types of equipment that other users can buy or lease directly from suppliers, as well as the conditions for such arrangements. The DBP has very detailed and thorough rules/regulations regarding equipment design and construction, and it is particularly sensitive to interconnection(s) of subscriber equipment to public networks. The very lengthy and thorough equipment-approval procedures have come under criticism for inhibiting the introduction of innovative products and for leading to high equipment prices in the FRG. There is interest in the USA experiment with an open interconnect market, but any significant change in DBP terminal equipment approval and interconnect procedures would require major political initiative(s).

The introduction of certain new type services (such as CATV) and the future of these services is currently in somewhat of a confusion because pressures from major German political parties are opposing "premature attempt(s) to pre-judge political and social questions about the desirability of introducing such services."

A.8 CURRENT STATUS AND ANNOUNCED PLANS FOR TELECOMMUNICATIONS IN FRG

The steady but relatively slow growth in telecommunications in the past in FRG as compared with the USA, Canada, etc., is an indication that until recently its development has not been a leading national priority. There is, however, an increasing awareness of the importance of telecommunications as an infrastructure for modern society, and as an industry in itself.

Total revenues of the DBP (postal and telecommunications) rose from $7.7 billion in 1970 to $18.6 billion in 1978 and to an estimated $20.4 billion in 1979, of which $13.7 billion came from telecommunications. From 1977 to 1979, telecommunications revenues grew at the rate of 7.9%/year. These substantial telecommunications profits of recent years are now accompanied by several tariff reductions and changes in the tariff structure.

In terms of penetration, the German telephone network is comparable to that of Great Britain, but well behind that of the USA or Sweden. As mentioned, it is fully automated, and all subscribers have access to international direct dialing. Residential demand for telephone service has been increasing toward the stated objective of at least one telephone in every household by the mid-1980's. The DBP expects that demand for public telephone equipment and services will level off by the mid-1980's, when the majority of households will already have a telephone. Thus prospects for the growth in tranmission bandwidth and associated facilities for the public telephone network will depend on new services beyond that time frame.

The DBP is currently implementing new services over the existing telephone networks; e.g., Telefax service was introduced relatively recently, its typical transmission rate of three minutes per page is suitable for many purposes. Further standardization efforts will probably result in a proliferation of the approximately 4000 facsimile sets currently in use within FRG. Higher transmission speeds of alpha-numeric text pages and additional advantages based on the features of associated (micro-) processor(s) can be achieved with communicating typewriter(s). For Germany, the standard transmission speed of 2400 bps has been selected which allows transmission of an average page in 1/8 minute. Such a combination of Telefax plus communicating typewriter(s) could possibly provide a form on electronic mail. However, equipment which is expensive relative to the telephone handset would be needed, thereby limiting most initial uses to interoffice communications.

Telegraph traffic (which is handled exclusively by the DBP on the automatic telex network) is in a slowly declining trend, but the decline is lessening lately. It is believed that the rate will stabilize around 1985 at about 7 million messages per year.

Demand for already extensive telex service continues to grow at a rate of 4 to 5 percent per year. By now (mid-1981) it is fully incorporated into the DBP's new Integrated Data Network (IDN), which is based on the transparent, circuit-switched, stored program controlled Electronic Data System (EDS) exchanges which were first put into service in 1975. IDN offers its subscribers transmission rates from 50 bps to 48 Kbps. In early 1979, 20 EDS exchanges provided an overall capacity of 200,000 ports. Although the bulk of demand for data communications is expected to be satisfied by such circuit-switched facilities as IDN, there is a distinct need for packet-switched services (which the DBP is planning to introduce in the not too distant future). Telex facilities now include electronic teleprinters with new printing mechanisms and private branch exchanges which permit terminals to be located close to the end users. IDN uses digital communications links between EDS exchanges (mostly 2.048 Mbps and some at 8.448 Mbps) and can carry asynchronous telex and low-speed data as well as synchronous medium- and high-speed data. Except for the introduction of new components, development appears to be temporarily halted, although DBP plans still call for the bulk of data services to use IDN. The variety of data rates will most likely be favorable to introduction of a variety of other services.

The DBP also has been active in a number of national and international data network activities that are based upon packet-switching technology. Access to the Tymnet and Telenet services in the USA has been provided since 1977 from the switched telephone network (300 bps) and the 200-300 baud classes of the switched Datex network. The DBP also participates in Euronet, the international European network which European PTTs are establishing under contract from the Commission of European Communities.

In 1980 the DBP initiated service on a public national packet-switched network (based on the SL-10 exchange of Northern Telecom). Preliminary estimates anticipate about 13,000 ports in this network by about 1985, but the number and the location of nodes and concentrators are still indefinite. This network will provide the CCITT-recommended interface X.25 (LAP B).

Facilities planned for this Packet-Switched Network include data rates of 110 to 300, 1200, 4800, 9600, and 48,000 bps, with access from the public switched telephone network (up to 1200 or 2400 bps) plus the telex and circuit-switched data networks.

The DBP Videotex service called "Bildschirmtext" is similar to the British Viewdata; it works over an unmodified telephone (or CATV) network to access data banks of text. An attachment is required between it and the television set to display the text and/or still frame pictures, plus a modem is necessary to convert the signals transmitted via the telephone handset. Subscribers can request a particular page using the telephone keypad, where-upon the response is transmitted over the network and the requested page is displayed on the television set. This type of service can be provided along with telephone, Telefax, and other services.

The "Commission on the Future of Telecommunications" has discussed new forms of telecommunications for telephone, data, and CATV networks. These are shown in Figure A.7-1. But other than in areas of poor reception, the demand for cable television services cannot be met because the current national political environment is not conducive to development of new CATV services. Many political, government, and private interests in the FRG are involved in a conflict about cable television (about its scope, ownership, and regulation, and whether it would be even advantageous for the country). Consequently, the future of this particular item will be determined by the outcome of a number of major issues, which include:

o   What the relative roles should be of direct broadcast satellite and cable networks for TV transmission and distribution;

o   Whether privately owned TV broadcasting should be permitted;

o   What control newspaper publishers should have over CATV networks and programming.

In recent years, contradictory policy statements and conflicting (announced) plans have shown that, for the moment, the development of CATV networks (as distinct from master antenna systems) is at a standstill.

In 1976, the Federal Government's independent Commission for Development of Technological Communications Systems recommended the establishment of four broadband cable television networks (with 2-way capability). The sites for

	Form of Telecommunication	Flow of Information		Network	Output on
Text	Communication typewriter	⟵⟶	Dialog	Data-or-Telephone	Paper (P)
Text	Video text	●⟶O	Distribution	TV-OR-CATV-	Screen (S)
Text	View data (Bildschirmtext)	●⟶O	Retrieval	Telephone-	S
Still picture	Facsimile	⟵⟶	Subscrib. to Subscriber	Telephone-or-data-	P
Still picture	Facsimile newspaper	●⟶O	Distribution	Telephone-or CATV-	P
Still picture	Video-still picture	●⟶O	Retrieval	CATV-	P
Still picture	Slow-scan TV	●⟶O	Retrieval	Telephone-	S
Still picture	Electronic mail	⟵⟶	Subscrib. to Subscriber	Telephone-or data	P
Tele-metering	Remote control	●⟶O	Center to Subscrib.	Telephone-data-or CATV-	Remote control equipment
Tele-metering	Remote metering	●⟵O	Collection		

●Center   oSubscriber

FIGURE A.7-1

Potential New Types of Telecommunications
Services over Existing FRG Networks

these projects are Berlin, Ludwigshafen/Mannheim, Munich, and Dortmund. In late 1979, the involved state governments were still trying to decide who should finance the networks and programs and how (or whether) private organizations should be involved. However, just recently the DBP has announced that it is prepared to take over financial and technical responsibility for these networks; hence, a high probability exists that these networks will be implemented in the 1981-1985 time frame.

Announced DBP plans for extending telecommunications transmission networks and services at this time include the following:

o   Expansion of the telephone network to provide one telephone per household by the mid-1980's;

o   Expansion of the IDN to accomodate growth in telex services and the expected rapid growth in data services;

o   Introduction of packet-switched data services;

o   Participation in the European communications satellite system for international telephony and TV transmission;

o   New or expanded mobile radio networks and associated connecting links to meet unsatisfied demand.

Despite the above discussed controversy over CATV, the DBP has also announced intentions for developing several major pilot projects for new services, notably interactive teletext and high-capacity interactive cable television.

A most recent (mid-1981) DBP announcement indicated that the Bundespost will commence work on the introduction of a new type of telecommunications system. The system involved is designated "BIGFON," a wideband integrated glass-fiber telecommunications network. A distinguishing feature of the BIGFON plan is that is envisions fiber-optic transmission to individual subscribers' premises, in addition to the more conventional application of fiber optics to heavy trunk routes. The first field tests are expected by the end of 1981 in Berlin, Dusseldorf, Hamburg, Nurnberg, and Stuttgart. Full scale conversion to optical fiber transmission systems could commence around 1985/1986 and, depending on public acceptance of the new system, it is estimated that it will take 20 to 40 years to complete.

The FRG Government believes that by 1985, optical transmission systems can be offered at about the same price as current conventional networks. Consequently, the DBP specifications for the BIGFON project include requirements for:

o   Simultaneous transmission over a single circuit connection of telephone, data, text, and drawings, 2-4 television broadcasts, 24 stereo radio programs and picture-telephone (video phone)

o   Development and production of peripheral equipment such as digital telephones, viewdata decoders, and modified TV receivers (as terminals for video phones).

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        L. 65-10, 12, 14, 16, 18, 20; L. 67-08, 10, 12, 14, 16, 18,
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